550.6133
1

BULLETIN
OF
The Geological Society of America

VOLUME 60

NUMBER 12 Part 1

DECEMBER 1949

PUBLISHED MONTHLY BY THE SOCIETY

COUNCIL

President

WILLIAM W. RUBEY, Washington, D. C.

Past President

CHESTER R. LONGWELL, New Haven, Conn.

Vice-Presidents

CHESTER STOCK
Pasadena, Calif.

ROBERT B. SOSMAN
Westfield, N. J.

WINIFRED GOLDRING
Albany, N. Y.

JOHN W. GRUNER
Minneapolis, Minn.

Secretary

H. R. ALDRICH, 419 West 117 Street, New York, N. Y.

Treasurer

J. EDWARD HOFFMEISTER, Richester, N. Y.

Councilors

(Term expires 1950)

GEORGE M. FOWLER
Joplin, Mo.

F. J. PETTIJOHN
Chicago, Ill.

EARL INGERSON
Washington, D. C.

(Term expires 1951)

JOHN W. AMBROSE
Toronto, Canada

S. W. MULLER
Stanford University, Calif.

THOMAS B. NOLAN
Washington, D. C.

(Term expires 1952)

E. F. DAVIS
Los Angeles, Calif.

J. HOOVER MACKIN
Seattle, Wash.

RICHARD J. RUSSELL
Baton Rouge, La.

COMMITTEE ON PUBLICATIONS

A. S. WARTHIN, JR., *Chairman*
K. K. LANDES
H. R. ALDRICH, *Editor-in-Chief*
AGNES CREAGH, *Managing Editor*
C. L. MOODY
} *Conferees*

Vor

Bulletin
of
The Geological Society of America

VOLUME 60 December 1949 NUMBER 12, Part 1

CONTENTS

	Pages
Diffusion of ions through intergranular spaces in water-saturated rocks. By R. M. Garrels, R. M. Dreyer, and A. L. Howland	1809–1828
Terrain diagrams of the Philippine Islands. By Philip B. King and Edith M. McKee	1829–1836
Seismic evidence for the fault origin of oceanic deeps. By Hugo Benioff	1837–1856
Geological reconnaissance of the Island of Margarita, Venezuela. By H. H. Hess and John C. Maxwell	1857–1868

Subscription $15 per year.

Publication Office: Mt. Royal & Guilford Aves., Baltimore 2, Md.

Communications for publication should be addressed to The Geological Society of America, Dr. H. R. Aldrich, Secretary, 419 West 117th Street, New York 27, N. Y.

NOTICE.—Four weeks notice of change of address is necessary. In accordance with the rules established by the Council, claims for non-receipt of the preceding number of the Bulletin must be sent to the Secretary of the Society within three months of the date of the receipt of this number in order to be filled gratis.

Entered as second-class matter in the Post-Office at Baltimore, Md., under the Act of Congress of July 16, 1894.

Accepted for mailing at special rate of postage provided for in Section 1103 Act of October 3, 1917, authorized on July 8, 1918.

PAPERS IN PRESS FOR FORTHCOMING ISSUES

CORRELATION OF THE CRETACEOUS-TERTIARY TRANSITION IN SASKATCHEWAN AND ALBERTA. By Loris S. Russell

LAVA FLOWS IN THE GRAND CANYON OF THE COLORADO RIVER, ARIZONA. By John H. Maxson

CONTACT-METAMORPHIC EFFECTS OF TRIASSIC DIABASE AT SAFE HARBOR, PENNA. By Randolph W. Chapman

STRUCTURE AND PETROLOGY OF THE LOVEWELL MOUNTAIN QUADRANGLE, NEW HAMPSHIRE. By M. T. Heald

A geologic map, in color, accompanies this paper. Separate copies of the map, unfolded and in tubes, are available (25 cents per copy). Remittance should be sent with orders.

PHYSIOGRAPHIC FEATURES OF THE PANAMINT RANGE, CALIFORNIA. By John H. Maxson

DISTRIBUTION OF RADIOACTIVITY IN GRANITES AND POSSIBLE RELATION TO HELIUM AGE MEASUREMENTS By Patrick M. Hurley

GEOLOGIC CROSS SECTION OF THE CARDILLERA DE LOS ANDES (ARGENTINA-CHILE). By F. González Bonorino

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 60, PP. 1809–1828, 10 FIGS. DECEMBER 1949

DIFFUSION OF IONS THROUGH INTERGRANULAR SPACES IN WATER-SATURATED ROCKS

BY R. M. GARRELS, R. M. DREYER, AND A. L. HOWLAND

CONTENTS

	Page
Abstract	1809
Introduction	1810
Acknowledgments	1811
Effective distance of diffusion	1811
Rate of advance of a finite concentration front	1811
Experimental procedure	1811
Results and discussion	1812
Depth of penetration and rock properties	1812
Depth of penetration as a function of temperature	1814
Depth of penetration as a function of concentration	1814
General solution of the problem of maximum depth of penetration under assumed conditions	1816
The diffusion coefficient	1817
Problem of mixed salts and individual ionic diffusion coefficients	1818
General equation for maximum distance of penetration	1819
Sample problems	1820
Amount of diffusion	1821
Experimental	1821
Discussion	1825
The A'/l' ratio	1825
Quantity of solute delivered through rocks	1826
Conclusion	1827
Summary	1828
References cited	1828

ILLUSTRATIONS

Figure	Page
1. Depth of penetration of a finite concentration front of potassium permanganate solution into several different limestones at 25°C	1813
2. Depth of penetration of a finite concentration front of potassium permanganate solution into several different limestones at 25°C	1814
3. Effect of temperature on depth of penetration of a finite concentration front of potassium permanganate solution into the Fort Riley limestone	1815
4. Effect of concentration on the depth of penetration of finite concentrations of potassium permanganate solution into the Fort Riley limestone	1815
5. Distance of movement of concentration fronts of HCl during various time intervals	1816
6. Graph showing variation to be expected in D with changing concentration	1817
7. Error integral values	1820
8. Schematic diagram of geologic conditions under which steady state diffusion will develop	1822
9. Concentration gradient from fissure to adjacent parallel vein at time first effective concentration front reaches vein and when a steady state is attained	1822
10. Sketch of diffusion cell used in determining effective porosity of limestone cores	1823

TABLES

Table	Page
1. Chemical analyses, permeabilities and porosities of limestones used in diffusion studies	1812
2. Diffusion coefficients (cm^2/day) for individual ions compared at infinite dilution	1819
3. Diffusion of KCl through limestones	1824

ABSTRACT

One of the mechanisms of transfer of material through water-saturated rocks is solute diffusion from places of high concentration to places of lower concentration. The distance of movement through rocks of given concentration fronts has been studied experimentally as a function of time, temperature, and concentration of the reservoir. The accord of the experimental work with general diffusion theory has made it possible to present a nondimensional equation for the movement of diffusing ions through rocks. This equation makes it possible to calculate the distance of movement of selected concentration fronts over a wide range of solution composition. The rate of advance of a given concentration front is independent of the permeability or porosity of the limestones studied, but the amount of material transferred depends upon the porosity in the direc-

tion of diffusion. Methods of measuring this porosity are discussed, and values determined for several limestones. Solution of several sample problems indicates that solute diffusion through intergranular spaces in rocks is a more effective geologic process, even at low temperatures, than is generally believed.

Introduction

Many geologic phenomena have been interpreted as the result of the movement of large quantities of material long distances through rocks. Extensive dolomitization, silicification, and pyritization, for example, have been attributed to such a process. The mechanisms which have been suggested are too numerous to mention here, but for relatively low temperatures and pressures, two chief mechanisms are quite generally accepted: (1) Transfer of material in solution in water by bodily movement of the solution through the rock pores. (2) Transfer of material in solution in water as a result of differential movement of solute and solvent.

A great deal of study of the first mechanism has been done, and the variables which control the permeability of a rock are well known. On the other hand, transfer by relative movement of solvent and solute has received little attention. This latter process may well be termed "solute diffusion" to distinguish it from the many other processes which fall under the general term of diffusion. Bateman (1942, p. 95) has described the essential features of the process tersely. Discussing the replacement of an unfractured pyrite cube by chalcocite, he says of the mechanism of supply of copper to the unaltered pyrite:

> "Diffusion is probably the answer. This is the movement of molecules in a solution from a point of supply to a point of deposition or from a place of higher to one of lower concentration. Particles of molecular size can move through a layer where a bodily flow of solution could not. But diffusion is known to be exceedingly slow and to act only over short distances. Therefore, it cannot be a means of transporting large quantities of replacing substances over long distances; it is incompetent by itself to build up large mineral deposits. However, it is an effective process for supplying and removing the products and by-products of replacement over the short distances at the actual front of replacement, whereas voluminous moving solutions could not gain entry."

The basis for his statement that "diffusion is known to be exceedingly slow and to act only over short distances" is not cited specifically, and we could not find any references in the literature which appeared to be sufficient evidence for the statement, although a number of related experiments have been performed. Chief among these is the work of Duffell (1937), who studied the rate of penetration of a number of substances, including ionized salts, into rocks; and that of Brown (1947), who made a number of tests of the rate of penetration of colored solutions such as inks into rock pores. Bowen (1921) studied rates of diffusion in high-temperature silicate solutions, but his work is difficult to apply to water solutions because of the high viscosity of his mixtures. Both Duffell and Brown were unimpressed by the effectiveness of the process; Duffell's work may have been the basis for Bateman's statement. Both obtained some quantitative data, but neither attempted to study the diffusion process systematically as a function of time, temperature, and concentration of solutions.

The great present interest in the possibility that "solid diffusion" may be an effective process in the replacement of large volumes of rock was an added incentive to further investigations of diffusion through intergranular spaces in rocks; before appealing to a new mechanism, it seemed worthwhile to delimit quantitatively the possibilities of the old. The work presented below will serve as a quantitative guide to the effectiveness of solute diffusion in low-temperature processes and will indicate, although purely by extrapolation, something of the magnitude of the effects to be observed at higher temperatures.

The investigations described in this paper were made with the purpose of delimiting the maximum effectiveness of the diffusion process. The many variables in geologic processes make it generally possible to establish maxima or minima only by assuming conditions agreed upon as representing extremes. The paper is divided into two parts. The first is a discussion of the maximum distance over which diffusion can be effective, the second a determination of

the maximum amount of material which can diffuse through rocks.

ACKNOWLEDGMENTS

This work was carried on under a grant from the Penrose Fund of the Geological Society of America. Much of the experimental data was gathered by Margery Mooberry, Dorothy Dietrich, and Rose Annos of Northwestern University. Chemical analyses were made by R. T. Runnels of the State Geological Survey of Kansas. W. C. Krumbein of the Department of Geology, Northwestern University, A. A. Frost of the Department of Chemistry, and George Brown of the Department of Chemical Engineering, Northwestern University, offered many helpful suggestions. The manuscript was read by T. S. Lovering and Earl Ingerson of the U. S. Geological Survey; by G. W. Morey of the Geophysical Laboratory, and by J. S. Brown of the St. Joseph Lead Company. They made numerous pertinent suggestions and criticisms.

EFFECTIVE DISTANCE OF DIFFUSION

Rate of Advance of a Finite Concentration Front

Both Duffell and Brown studied "free diffusion"—that is, the rate at which a certain small finite concentration front moved outward from a reservoir of higher concentration. Brown allowed solutions to move into dry rocks, so that the effect of capillarity was important, but Duffell immersed the rocks in colored liquids or solutions containing ionized salts, allowing the ions or molecules to diffuse into the saturated rocks. It is important to stress that there is no bodily movement of the solution in these experiments; the transfer of material is entirely by relative movement of solute and solvent. The measurements are based upon recognition of a color boundary of one kind or another; consequently they do not truly measure the maximum penetration of the diffusing material, but rather the movement of some small finite concentration.

We conducted a series of experiments similar to those of Duffell, but over a wider range of the variables. The group of limestones chosen as materials for the experiments covered a fairly wide range of permeability and porosity. Chemical analyses of some of these limestones are included in Table 1.

After a considerable investigation, potassium permanganate solution was selected for the study. A number of tests showed that its color boundary was recognizable at lower concentrations than that of other solutions tested, and, more important, there was no appreciable reaction between the solution and the limestone.

Experimental Procedure

Small cylinders of limestone 2 cm. in diameter and 1 cm. high were used. Their porosity and permeability were determined before the diffusion study was made.

POROSITY: The cores were dried at 110°C. for several days and weighed. Then they were immersed in distilled water until they reached a new constant weight. The increase in weight was converted to water volume, and this volume assumed to be a measure of the original accessible voids in the rock. The percentage relation of this volume to the total core volume is the listed porosity (Table 1).

PERMEABILITY: The cores were mounted in plastic cylinders and distilled water forced through them from a reservoir, using nitrogen pressure as the drive. The volume of water passed was measured directly in a buret; the pressure head from the nitrogen tank gauge. From these data and the core dimensions the permeability was calculated. Plots of volume delivered versus time were linear in all cases.

DIFFUSION RATE: The cores were soaked in distilled water again, then placed in a shallow flat-bottomed dish. Potassium permanganate solution was added until only the top surface of the cylinder was exposed. At once the ions began to move radially inward, and the color boundary was traced across the top surface. Reproducible measurements were obtained by recording the inner limit of discernible purple as a function of time. At first glance, the method seems crude and subject to many errors, especially from evaporation at the surface of the cylinder. Checks were made by immersing the cylinders entirely and sectioning them after a time interval. The results agreed closely with those from observation of the surface. Also,

data by several different observers on cores of the same limestone checked very well.

Table 1.—Chemical Analyses, Permeabilities and Porosities of Limestones Used in Diffusion Studies

GREENHORN LS.
(Pfeifer)
Cretaceous, Central Kansas

Porosity = 34.0%
Permeability = 3 to 9 millidarcys

FORT RILEY LS.
Permian, Eastern Kansas
Chemical analysis*

SiO_2	4.92%
Al_2O_3	0.62
Fe_2O_3	0.78
CaO	52.46
MgO	0.05
Loss on ignition at 1000°C.	41.30
Moisture at 140°C.	0.23

Porosity = 18.2%
Permeability = 0.6 to 0.8 millidarcys

OREAD LS. B
(Toronto Member)
Pennsylvanian, Eastern Kansas
Chemical analysis*

SiO_2	3.22%
Al_2O_3	0.71
Fe_2O_3	5.20
CaO	38.60
MgO	9.39
Loss on ignition at 1000°C.	42.46
Moisture at 140°C.	0.07

Porosity = 3.79%
Permeability = too low for satisfactory determination

OREAD LS. A
(Leavenworth Member)
Pennsylvanian, Eastern Kansas
Chemical analysis*

SiO_2	3.18%
Al_2O_3	0.37
Fe_2O_3	2.18
CaO	51.88
MgO	0.55
SO_3	0.20
Loss on ignition at 1000°C.	40.71
Moisture at 140°C.	0.08

Porosity = 11.4%
Permeability = 0.007 to 0.01 millidarcys

FUNSTON LS.
(Cottonwood)
Eastern Kansas
Chemical analysis*

SiO_2	8.03%
Al_2O_3	1.59†
Fe_2O_3	1.14
CaO	50.14
MgO	0.11
Loss on ignition at 1000°C.	38.62
Moisture at 140°C.	0.35

BOXBERGER LS.
(No data)

* Analyses by R. T. Runnels, Kansas State Geological Survey.
† Not corrected for TiO_2 and P_2O_5.

Results and Discussion

Depth of penetration and rock properties.—The results of the experiments on the depth of penetration of permanganate solution as a function of time are shown in Figure 1. All these data are at a constant concentration of the external solution of 0.43 molar, and at a temperature of 25°C., so that the variations in rate owing to the differences in rock character can be noted. Penetration of the lowest visible concentration front is at a continuously decreasing rate in each case, and the most remarkable fact is that the order of magnitude is about the same for all the limestones, although their permeabilities differ tremendously (Table 1). Further, there is no obvious relation between permeability and rate of penetration; the Greenhorn limestone, which was penetrated at an intermediate rate, is much more permeable than any of the others. After considering the data, we decided that the rate of penetration of a particu-

lar limestone might well be independent of the permeability, because whereas the rate of flow of a solution through a rock is a function of the size of passageways, the rate of solute diffusion should not be affected unless the intergranular openings are narrower than a few ionic diameters. However, there are significant differences in the rates; that for the Cottonwood limestone is several times as great as that for the Boxberger. To what may these differences be attributed?

Three chief factors occur to us. First, the rates of movement of two concentration fronts may be identical, but if one front must move deviously through extremely irregular pores, while the other moves in straight passages, the apparent linear rate of the former will be much less than that of the latter. Microscopic examination of the cores was not helpful in determining the nature of the openings. Second, there is no real assurance that one limestone may not adsorb or absorb larger quantities of diffusing ions than the other, even though preliminary tests showed no measurable reaction between permanganate solution and calcite. Third, the subjective nature of the observations, in which the faintest visible color boundary was followed, gave consistent measurements on any one limestone sample, but makes it possible that the concentration front followed on one sample was different from that on the other.

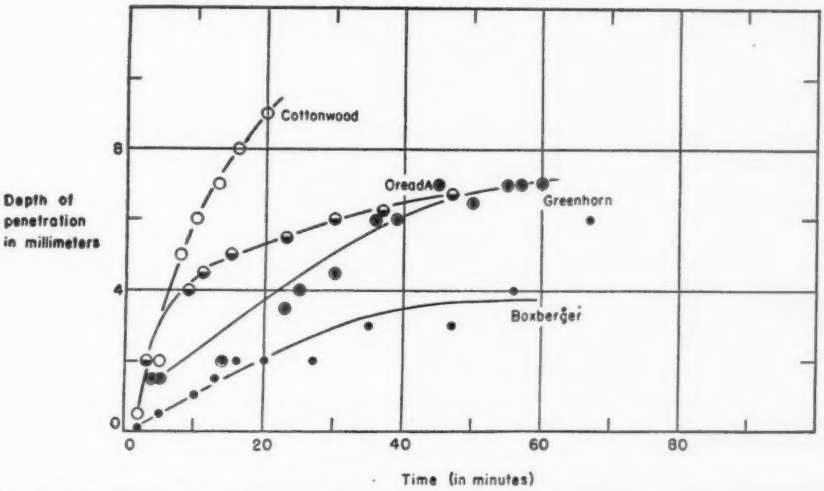


FIGURE 1.—DEPTH OF PENETRATION OF A FINITE CONCENTRATION FRONT OF POTASSIUM PERMANGANATE SOLUTION INTO SEVERAL DIFFERENT LIMESTONES AT 25°C.
Temperature 25°C. Concentration of $KMnO_4$ 0.43 M.

It is difficult to assess the magnitude of such errors, but our best judgment indicates that they may well account for the variations in rate observed. If this judgment is valid, then the rate of penetration of non-reacting ions through intergranular openings in these water-saturated rocks is independent of the porosity or permeability of the rock. Obviously, the amount of material moving through the rock depends upon the effective porosity in the direction of movement, and should be directly proportional to that area. Also, the amount should be independent of pore size except for pores approaching the diameter of ions. The problem of amount will be considered later.

The theory of free diffusion indicates that the relation between the time that diffusion has continued and the distance of movement of any given concentration front can be expressed as:

$$\frac{s}{\sqrt{t}} = K \qquad (1)$$

where s is the distance of movement from the reservoir, and t is time elapsed since the concentration front left the original boundary. If

0.05°C. The solution and cores were kept covered with a glass plate during the measurements to prevent evaporation loss.

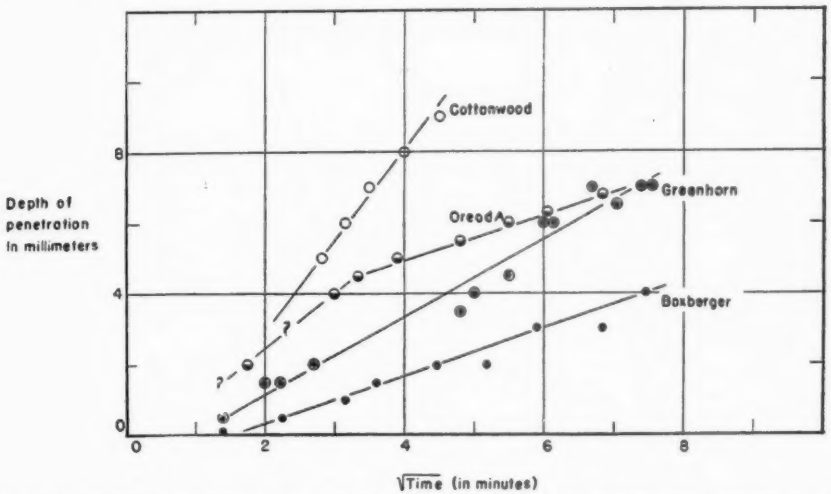


FIGURE 2.—DEPTH OF PENETRATION OF A FINITE CONCENTRATION FRONT OF POTASSIUM PERMANGANATE SOLUTION INTO SEVERAL DIFFERENT LIMESTONES AT 25°C.
Temperature 25°C. Concentration of $KMnO_4$ 0.43 M.

the experiments on the limestones fit this relation, considerable confidence can be placed in the conclusion that ionic movement through rock pores takes place independently of the size of the pores exactly as if no confining rock walls were present.

Equation #1 above can be written:

$$s = K\sqrt{t} \qquad (2)$$

Thus a plot of s against $\sqrt{t}$ should give a straight line, the slope of which is K. Figure 2 is such a plot, and shows reasonable agreement with the prediction.

Depth of penetration as a function of temperature.—Temperature was the second major variable studied. Figure 3 shows the effects of temperature upon the penetration of the permanganate solution into the Fort Riley limestone. The data were obtained by the same procedure described before, except that the cores and the solution were brought to the temperature of measurement prior to the experiment by immersion in suitable containers in a constant temperature bath regulated to

Each 10-degree rise in temperature causes an increase in slope of the penetration curve by a factor of about 1.35, which corresponds to an increase of about 3.5 per cent per degree. This is in fair accord with the theoretical change in rate, which averages 2–3 per cent per degree Centigrade (Taylor, H. S., 1924), and agrees very well with the maximum coefficient for strongly ionized substances. If the value of 3.5 per cent be accepted as a maximum, then the effect of temperature on depth of penetration can be expressed mathematically:

$$\frac{s_{t_1^\circ}}{s_{t_0^\circ}} = 1 + 0.035\,(t_1^\circ - t_0^\circ) \qquad (3)$$

where $s_{t_1^\circ}$ is the depth of penetration over a given time interval at a given concentration at temperature t_1°, and $s_{t_0^\circ}$ is the depth of penetration over the same time interval for the same concentration at a lower temperature t_0°.

Depth of penetration as a function of concentration.—The effect of a change in concentration of the permanganate on depth of penetration is shown in Figure 4. The rate is changed very

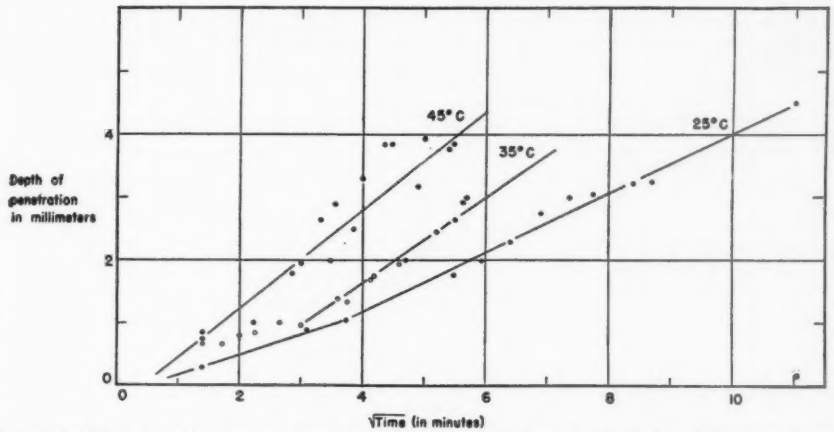


FIGURE 3.—EFFECT OF TEMPERATURE ON DEPTH OF PENETRATION OF A FINITE CONCENTRATION FRONT OF POTASSIUM PERMANGANATE SOLUTION INTO THE FORT RILEY LIMESTONE
Concentration of $KMnO_4$ 0.25 M.

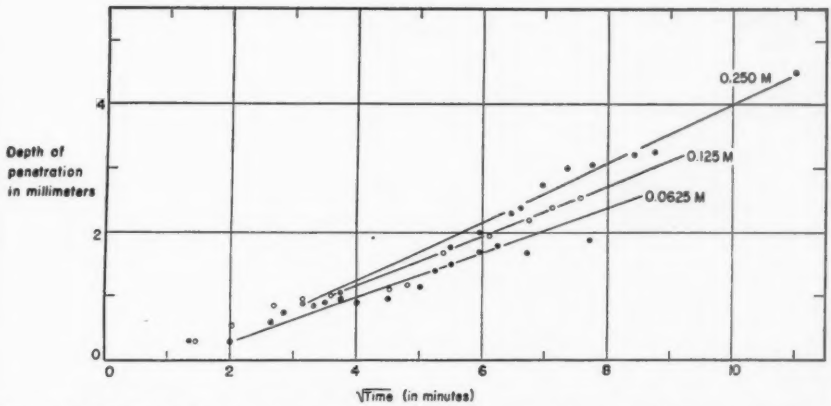


FIGURE 4.—EFFECT OF CONCENTRATION ON THE DEPTH OF PENETRATION OF FINITE CONCENTRATIONS OF POTASSIUM PERMANGANATE SOLUTION INTO THE FORT RILEY LIMESTONE
Temperature 25°C.

little by increase in the concentration of the reservoir, if the front has a very low concentration relative to that of the reservoir. The effect of concentration of the reservoir becomes progressively more important as the movement of fronts of higher and higher concentration is studied. This relation is not shown clearly by our data, which have a relatively narrow range of reservoir concentration and show the movement of a single front. The work of Wilke and Strathmeyer (1926), who ran experiments on the diffusion of several acids in a vertical tube shows it clearly. In one experiment, 12 N hydrochloric acid was diffused into pure water, and the movement of the various concentration fronts followed by observing floats of different densities, each of which floats travelled with a certain concentration front. As the experiment proceeded, the HCl diffused upward into the water and the water downward into the HCl, so that the highest density floats actually moved downward, following the front of undiluted

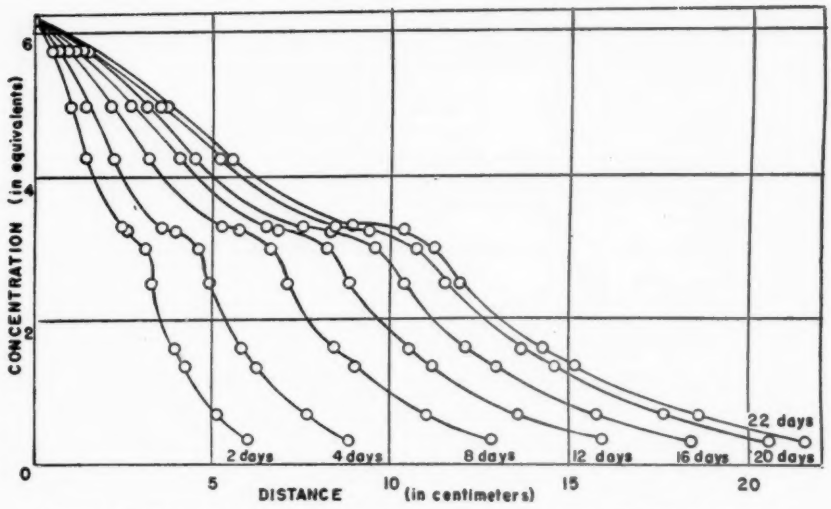


FIGURE 5.—DISTANCE OF MOVEMENT OF CONCENTRATION FRONTS OF HCL DURING VARIOUS TIME INTERVALS
Data from Wilke and Strathemeyer (1926)

acid. However, since the movement of several concentration fronts was known, we deduced that the rate of advance of a front relative to a reservoir of fixed concentration could be obtained by measuring the rate of movement of one front relative to another. Figure 5 shows a plot taken from their data, of the movement of a number of fronts relative to the 6.1 normal front. It can be seen that the importance of a given change of reservoir concentration on the distance of movement of a concentration front decreases as the difference in concentration between the reservoir and the front considered increases. For example, the 0.3 N front moved 20.5 cm. relative to the 6.0 N front in 22 days and 17.7 cm. relative to the 5.0 N front, a difference of 14 per cent. On the other hand the 4.0 N front moved 5.2 cm. relative to the 6.0 N front and 2.5 cm. relative to the 5.0 N front, a difference of 52 per cent.

Unfortunately, then, no simple relation appears between the rate of penetration of a given front and the concentration of the reservoir, except that the movement of a front tends to become independent of changes of reservoir concentration when the ratio of reservoir concentration to front concentration is a large number.

General Solution of the Problem of Maximum Depth of Penetration Under Assumed Conditions

The general accord of the experimental work with diffusion theory makes it possible to expand the scope of the work from the diffusion of potassium permanganate into limestone to the problem of the maximum distance of travel of any salt through any rock. There are still gaps in knowledge of the specific behavior of some salts of interest, and also difficulties in treating the behavior of mixed electrolytes, but it is possible to give rough quantitative answers to many problems.

It has been shown that the distance of penetration of a diffusing salt which neither reacts with the rock nor is adsorbed by it is independent of the pore size, at least down to very small pores. The distance approached under ideal conditions is the distance reached when diffusion takes place through unconfined water. The actual distances (Fig. 1) differ from rock to rock, but they are of the same order of magnitude. Therefore it seems safe to conclude that the rates of the faster diffusing common salts through unconfined (essentially) water is a safe guide to the maximum distance of penetration through rocks in nature.

The diffusion coefficient.—The relative rates of diffusion of substances are commonly compared in terms of the diffusion coefficient D, which is defined by Fick's law:

$$\frac{dq}{dt} = -D\frac{dC}{ds} \qquad (4)$$

stances, and the distance of penetration of the same concentration fronts of two salts, all other conditions remaining identical, is proportional to the square root of the D values. Unfortunately for the sake of simplicity, D is not truly a constant for a given salt at a given temperature, but is somewhat dependent upon the salt con-

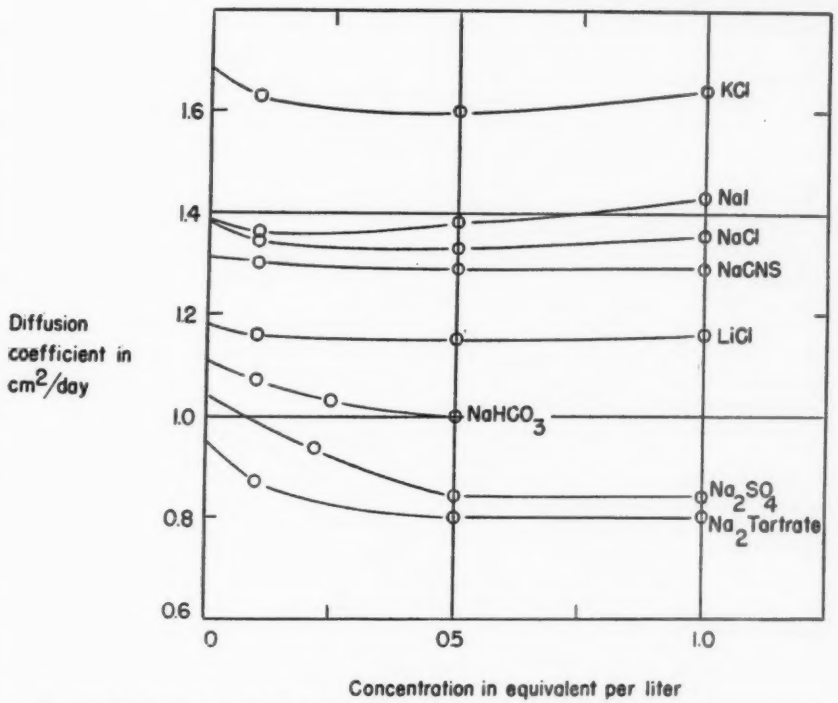


FIGURE 6.—GRAPH SHOWING VARIATION TO BE EXPECTED IN D WITH CHANGING CONCENTRATION
Data from Vinograd and McBain (1941)

where q is the quantity of material diffusing through a unit cross section, t the time, C the concentration, s the distance, and D the diffusion coefficient. The rate of transfer of material through a cross section is proportional to the concentration gradient, and the constant of proportionality is the diffusion coefficient. If q is given in equivalents per square centimeter, C in equivalents per cubic centimeter, t in days, and s in centimeters, then D has the dimensions of square centimeters per day.

Under comparable conditions, D values are a measure of the "diffusibility" of various subcentration. On the other hand, the range of values is not very great (Fig. 6). The change in slope in Figure 5 at concentrations of about 3 normal is a reflection of a maximum in D at that value.

Whatever the difficulties in ascertaining exact values of D, the relation holds, if the values are known:

$$\frac{s_A}{s_B} = \frac{\sqrt{D_A}}{\sqrt{D_B}} \qquad (5)$$

where s_A is the depth of penetration of a given front of salt A, and s_B is the depth of penetration

of the same front of a second salt B, all other conditions being identical.

Problem of mixed salts and individual ionic diffusion coefficients.—The question arises almost immediately in the geologist's mind: What is the effect on diffusion rates of the complex solutions so common in nature? What if the diffusing material is moving into a rock saturated with sodium chloride solution? Or if a mixture of sodium, calcium, and magnesium chlorides and sulfates is allowed to diffuse into a rock, will each salt behave as if it alone were present? Obviously not, for these salts are ionized. It would be impossible, in the first place, to state whether it was the calcium, the magnesium, or the sodium which should be considered to be present as the sulfate. And, unless this is known, no D value can be assigned for the salt.

Fortunately, Vinograd and McBain (1941) have worked out the theory of mixtures so that each ion of interest can be treated separately and its diffusion coefficient in the mixture determined. The details may be found in their paper, but the equations necessary for calculation are presented here.

First, they show that the diffusion coefficient of an individual ion at infinite dilution can be expressed by the Nernst equation:

$$D_i = RT\frac{u_i}{n_i} \tag{6}$$

where D_i is the diffusion coefficient in square centimeters per day, R the gas constant, T the absolute temperature, u_i the limiting equivalent conductance, and n_i the valence of the ion. As an example, the diffusion coefficient of H^+ can be calculated at 25°C by substituting 0.023 for RT, 349 mhos for u_i, and 1 for n_i. Then:

$$D_i = 0.023 \times \frac{349}{1} = 8.05 \text{ sq. cm/day}$$

For a single salt, Nernst's equation can be used with Haskell's modification to get the mean diffusion coefficient:

$$D = iRT \Big/ \left(\frac{1}{u_+} + \frac{1}{u_-}\right) \tag{7}$$

where i is the number of ions or ion complexes or molecules per equivalent of salt (i.e. for KCl i = 2; for $BaCl_2$ i = 1.5) for $CuSO_4$ i = 1), and u_+ and u_- are the limiting equivalent conductances of the ions. As an example, for HCl, using the values above plus the new value of 75.5 for the equivalent conductance of the Cl^-:

$$D_{HCl} = \frac{2 \times 0.023}{\frac{1}{349} + \frac{1}{75.5}}$$

$$= \frac{0.046}{0.00287 + 0.0132} = 2.86 \text{ sq. cm/day}$$

In a mixture, the diffusion coefficient of a selected positive ion is given by the formula:

$$D_+G_+ = RT\frac{u_+}{n_+}$$

$$\left[G_+ - n_+C_+\frac{\Sigma u_+G_+/n_+ - \Sigma u_-G_-/n_-}{\Sigma u_+C_+ + \Sigma u_-C_-}\right] \tag{8}$$

The parallel formula for a given negative ion is:

$$D_-G_- = RT\frac{u_-}{n_-}$$

$$\left[G_- - n_-C_-\frac{\Sigma u_+G_+/n_+ - \Sigma u_-G_-/n_-}{\Sigma u_+C_+ + \Sigma u_-C_-}\right] \tag{9}$$

For equation 8, where D_+ is the effective diffusion coefficient of the positive ion in question, G_+ the concentration gradient of the ion ($\frac{dc}{ds}$ in equivalents per liter), n is the valency of the ions, u the equivalent conductance in mhos of the ions, and C the concentration in equivalents per liter.

For example, if we are interested in the diffusion coefficient of H^+ in a mixture of 0.1 N HCl and 0.1 N KCl, substitution in the formula gives (assuming for convenience that the concentration gradient is equal to the concentration):

$$D_+ \times 0.1 = 0.023 \times \frac{349}{1}\left[0.1 - 1 \times 0.1\right.$$

$$\left.\frac{(349 \times 0.1/1) + (74.5 \times 0.1/1) - (0.2 \times 75.5/1)}{(349 \times 0.1) + (74.5 \times 0.1) + (0.2 \times 75.5)}\right]$$

$$= D_{H^+} = 4.20 \text{ sq. cm/day}$$

Thus H^+ would diffuse much more rapidly from a mixture of 0.1 HCl and 0.1 KCl than from 0.1 N HCl alone. This general formula

can be used for any mixture for which all concentrations and equivalent conductances are known.

For this work, it is necessary to know the maximum distance which a given ion can diffuse. Vinograd and McBain (1941) show that the general effect of mixtures is to speed up fast ions and to retard slow ones still further. In getting the maximum distance of penetration for an ion, it seemed fairly safe to use the Nernst value of its diffusion coefficient (Equation 6), the diffusion coefficient of an entirely freed ion. The basis for this conclusion is as follows. For H^+, alone, $D = 8.05$. However, H^+ is associated with slower-moving anions, and the actual value in mixtures, except for very exceptional conditions, is less than the 8.05. In terms of a mechanical model, the H^+ must wait for the slower-moving ions, because electrical equivalence must be maintained and it cannot go off by itself. Cu^{++}, on the other hand, is a slow-moving ion relative to many others. In a single salt, such as $CuCl_2$, the rate of movement of the Cu^{++} is faster than the value determined by the Nernst equation for Cu^{++} alone, but under almost any geologic conditions, other faster-moving positive ions will be present and the Cu^{++} will be left behind, as the fast-moving positive ions race off with the faster fraction of the Cl^-. In this case the value of D for the copper ion will drop far below its Nernst value.

Table 2 gives the D values for a number of ions of geologic interest, based on the Nernst equation for the diffusion coefficient of an individual ion.

General equation for maximum distance of penetration.—A summary of the relationships of the variables which control depth of penetration is given below:

$$s = K\sqrt{\text{time}} \qquad \text{(time relation)}$$

$$\frac{s_{t_1}}{s_{t_2}^{\circ}} = 1 + 0.035\,(t_1^{\circ} - t_0^{\circ}) \qquad \text{(temperature relation)}$$

$$\frac{s_A}{s_B} = \frac{\sqrt{D_A}}{\sqrt{D_B}} \qquad \text{(diffusion coefficient relation)}$$

All these relations are relatively simple, but the concentration relation is more complex. However, a general, nondimensional equation which includes all the major variables except temperature can be derived from the discussion of Fürth's work by Geddes in Weissenberger's "Physical Methods of Organic Chemistry" (1945). The equation is:

$$\frac{C_0 - C}{2C_0} = \textit{Error Integral}\left[\frac{s}{\sqrt{2Dt}}\right] \qquad (10)$$

where C_0 is the concentration of the reservoir, C the concentration of the moving front, s the distance of movement of the front from the original boundary, D the diffusion coefficient, and t the time since diffusion began. The equation can be solved readily for the distance of movement of any given concentration front from a reservoir of any concentration over any time interval if the diffusion coefficient of the salt or ion in question is known at the temperature of interest. Tables of error integrals are given in the Handbook of Chemistry and Physics (1947); the values are given here in graphic form (Fig. 7).

As an example of the use of this graph to solve a specific problem, consider the linear diffusion

TABLE 2. DIFFUSION COEFFICIENTS (CM^2/DAY) FOR INDIVIDUAL IONS COMPARED AT INFINITE DILUTION*

Ion	D_{25°	D_{100°
H^+	8.05	17.8
K^+	1.69	5.6
Ag^+	1.42	4.9
Na^+	1.15	
$\frac{1}{2}\,Pb^{++}$	0.81	
$\frac{1}{2}\,Ba^{++}$	0.73	2.8
$\frac{1}{2}\,Ca^{++}$	0.68	2.6
$\frac{1}{2}\,Sr^{++}$	0.68	
$\frac{1}{2}\,Cu^{++}$	0.64	
$\frac{1}{2}\,Zn^{++}$	0.63	
$\frac{1}{2}\,Mn^{++}$	0.63	
$\frac{1}{2}\,Fe^{++}$	0.63	
$\frac{1}{2}\,Ni^{++}$	0.63	
$\frac{1}{2}\,Co^{++}$	0.63	
$\frac{1}{2}\,Mg^{++}$	0.61	
OH^-	4.60	12.5
$\frac{1}{2}\,SO_4^{=}$	1.79	3.58
Cl^-	1.75	5.8
$\frac{1}{2}\,WO_4^{=}$	0.80	
MnO_4^-	1.44	

* Calculated from data from Landolt Bornstein Tabellen, 3rd ed., part 3, p. 2059, 1936.

of a 0.01 N front of KCl from a reservoir of constant concentration of 1.0 N over a time of 4 days at a temperature of 25°C. Then

$$\frac{C_0 - C}{2C_0} = \frac{1 - 0.01}{2} = 0.495$$

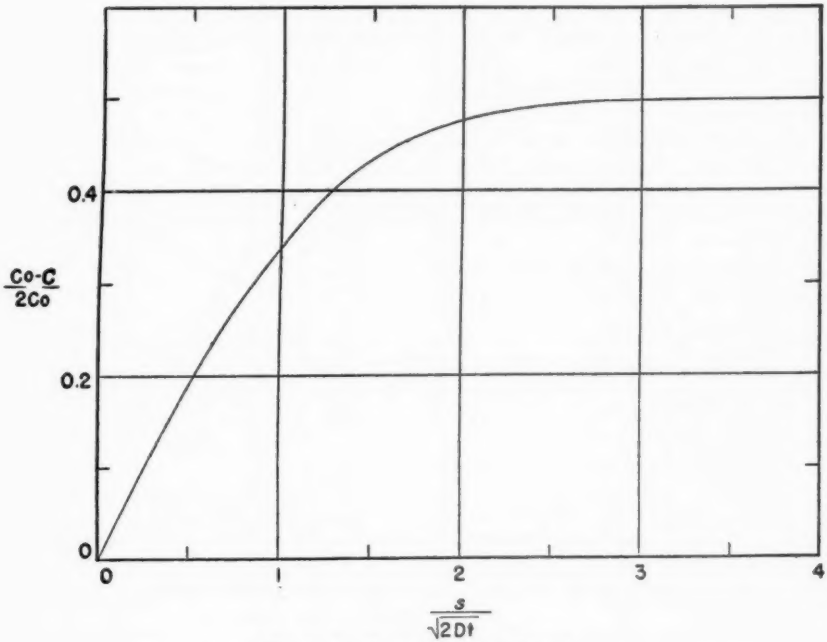


FIGURE 7.—ERROR INTEGRAL VALUES
Data from the Handbook of Chemistry and Physics, 30th Edition, p. 204–208

From Figure 7, the value of $\left[\frac{s}{\sqrt{2Dt}}\right] = 2.58$

Since D for KCl = 1.73, and t was given as 4 days:

$$\frac{s}{\sqrt{2 \times 1.73 \times 4}} = 2.58; \qquad d = 10\,\text{cm}.$$

Sample problems.—It may be of interest to solve two typical geologic problems.

First, let us assume that investigation of a Mississippi Valley type of galena-sphalerite deposit reveals a vein containing galena and calcite, bordered by sparse, finely disseminated galena in limestone country rock. The greatest distance at which disseminated galena occurs is 6 feet from the vein. What is the minimum time necessary for the formation of this deposit, assuming that the outermost galena represents the maximum distance of penetration of lead ions and that movement outward from the vein is entirely by diffusion?

The temperature of formation is of the order of 100°C, and modern theory makes the assumption that the concentration of lead ions in the solution was no more than 0.1 N appear reasonable. Lead ion has a diffusion coefficient which is intermediate relative to other ions expected in the vein solution, so no very great error should be made by assuming that its rate of diffusion is close to the limiting value (Table 2). No value is listed for Pb^{++} at 100°, but by analogy with those which are known at 100°, D for Pb^{++} must be very close to 3.0. Assume that the concentration of the vein solution re-

mained constant, and that a concentration front of 0.001 N is necessary to form the galena. The basic equation is:

$$\frac{C_0 - C}{2C_0} = \textit{Error Integral}\left[\frac{s}{\sqrt{2Dt}}\right]$$

Substituting the values above, and changing s in feet to centimeters:

$$\frac{0.1 - 0.001}{0.2} = 0.495 = E.I.\left[\frac{s}{\sqrt{2Dt}}\right]$$

Then:

$$\frac{s}{\sqrt{2Dt}} = 2.58 \qquad \text{(Figure 7)}$$

And:

$$\frac{183}{\sqrt{2 \times 3 \times t}} = 2.58$$

$$t = 842 \text{ days.}$$

It is clear, under the assumed conditions, that diffusion is competent to form the disseminated material; at least the 0.001 N concentration front would penetrate the requisite distance. Clearly, a longer time would be necessary to form appreciable quantities of galena at the distance of 6 feet.

Second, what is the maximum distance of penetration of a 0.001 front of the fastest-moving ion at the highest temperature for which D values are known, over a time interval of geologic magnitude? This problem is simply an attempt to define the greatest possible effectiveness of diffusion under conditions for which data are available. Let us use the limiting value for H^+ at 100° (Table 2) for the maximum D value, assume a constant reservoir of 1.0 N acid and a time of 1,000,000 years. Substituting in the basic equation:

$$\frac{1.0 - 0.001}{2} = 0.4995 = \textit{Error Integral}\left[\frac{s}{\sqrt{2Dt}}\right]$$

Then:

$$\frac{s}{\sqrt{2 \times 1\,7.8 \times 10^6 \times 365}} = 3.3 \qquad \text{(Figure 7)}$$

And:

$$s = 38.6 \times 10^4 \text{ cm.} = \text{approx. } 2\tfrac{1}{2} \text{ miles}$$

Therefore, even at 100°C, the fastest-moving ions from a fairly concentrated reservoir may travel very considerable distances indeed. It must be stressed that many assumptions are made: that the temperature of the rocks remained constant at 100° over the whole distance for the entire million years; that no reactive rocks were encountered along the way; that the passages through the rock were straight. The 2½ miles is the greatest distance the front could travel under these highly idealized conditions.

Amount of Diffusion

Experimental

After establishing the rate at which a finite concentration front travels through rocks, the next major problem is the measurement of the actual quantity of material which diffuses. The general problem can be illustrated by a geological model (Fig. 8) in which a solution of constant composition travels in a fissure. Diffusion proceeds laterally outward from the fissure until the diffusing material reaches another parallel fissure filled with pure water or reaches a place where it reacts with the rock and begins to precipitate.

The processes can be divided into three: (1) The diffusing ions move outward from the fissure until the smallest effective concentration front reaches either the fissure containing pure water or the rock with which complete reaction occurs. When this condition is reached, the concentration gradient from the central fissure to the boundaries is not linear (Fig. 9). (2) After the concentration front has reached the fissure of the reacting rock, diffusion continues but the front has been stopped. The higher-following concentrations begin to "catch up", and the concentration gradient gradually becomes linear (Fig. 9). (3) "Steady state diffusion" begins, and the rate at which material diffuses from the central fissure to the vein carrying pure water or to the reaction front becomes constant.

During stage 1, no material has yet diffused through the rocks and reached the second fissure; during stage 2, a steadily increasing amount is delivered, during stage 3, the amount reaches its maximum and remains constant. Therefore a measurement of steady-state diffusion through a rock section measures the maximum amount of material which can move

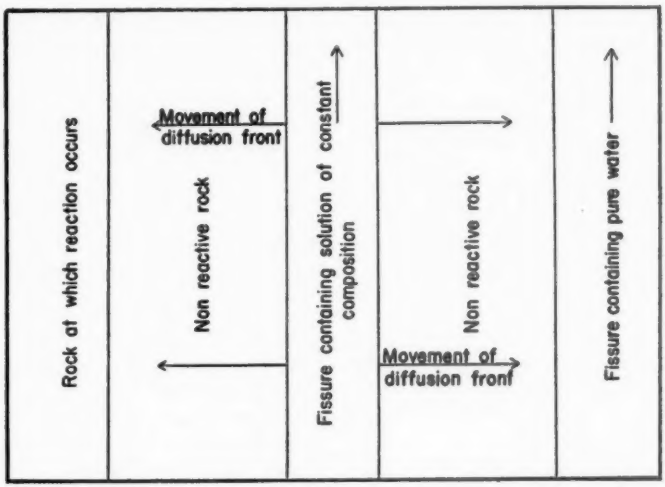

Rock at which reaction occurs
Movement of diffusion front
Non reactive rock
Fissure containing solution of constant composition
Non reactive rock
Movement of diffusion front
Fissure containing pure water

FIGURE 8.—SCHEMATIC DIAGRAM OF GEOLOGIC CONDITIONS UNDER WHICH STEADY-STATE DIFFUSION WILL DEVELOP

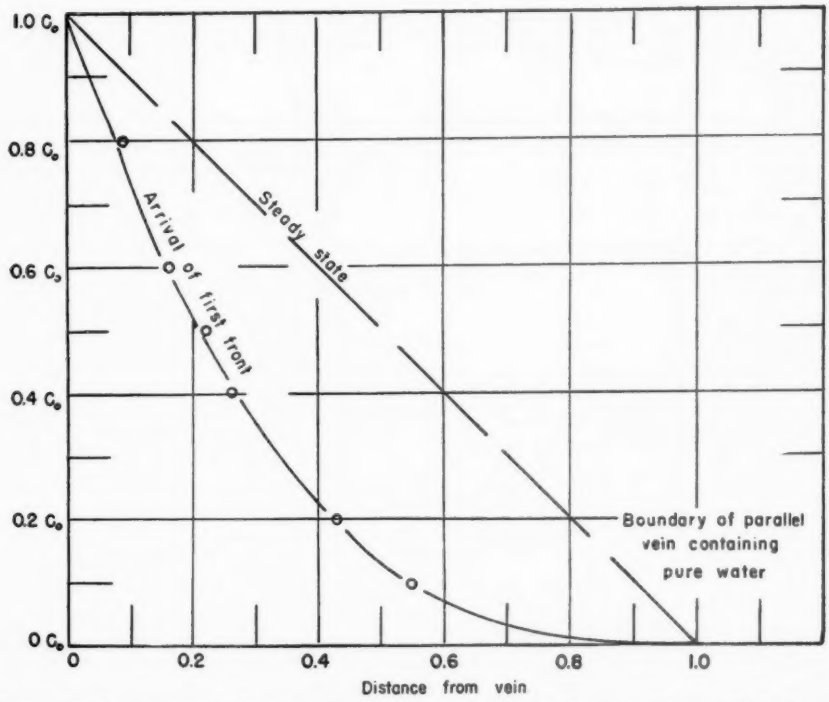


FIGURE 9.—CONCENTRATION GRADIENT FROM FISSURE TO ADJACENT PARALLEL VEIN AT TIME FIRST EFFECTIVE CONCENTRATION FRONT REACHES VEIN AND WHEN A STEADY STATE IS ATTAINED

through a rock by diffusion. It seems probable that in nature a steady state is achieved in many cases, for when ions diffuse and then react with a rock, the ions are removed at the site of reaction and a zero concentration effective material delivered under steady-state conditions. The difficulties of maintaining a reservoir of truly constant composition and a boundary of zero concentration in the other side of the rock should be obvious.

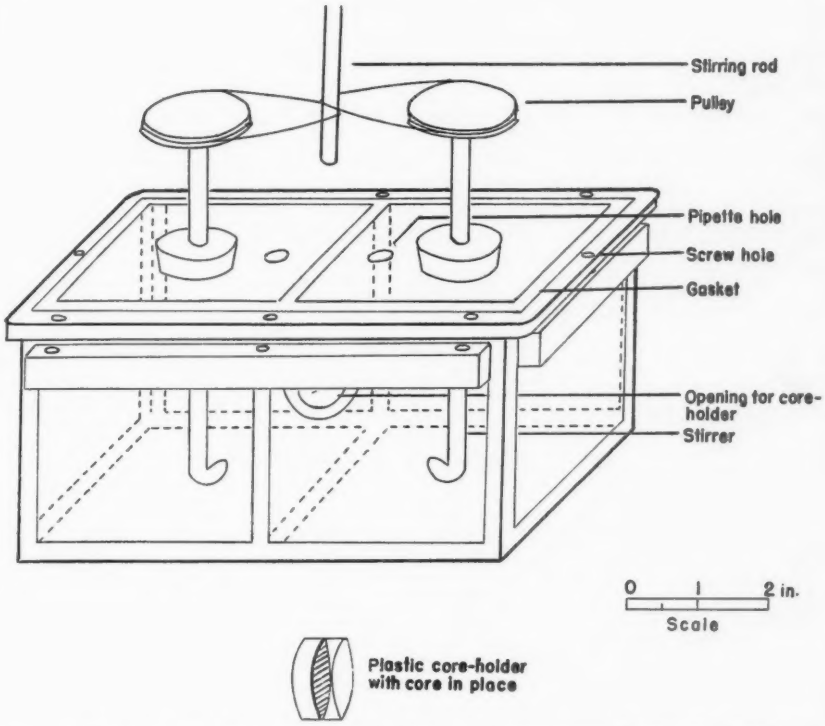


FIGURE 10.—SKETCH OF DIFFUSION CELL USED IN DETERMINING EFFECTIVE POROSITY OF LIMESTONE CORES

tively maintained in the reacting rock. It is perhaps less likely that the reservoir concentration remains constant, except in the case of fissures with appreciable flow. However, if the concentration of the reservoir decreases, or if the diffusing ions are not removed at the site of reaction or do not flow away in a second fissure, the amount of material transported by diffusion constantly decreases and is less than if a steady state is maintained.

It is practically impossible to achieve a steady state experimentally, but the measurements can be used to calculate the amount of

The measurements on steady-state diffusion were made by using short sections of limestone drill cores as diaphragms between two reservoirs, one of which was filled with a solution of known concentration, the other with distilled water. Analyses were made of the two sides at regular time intervals.

The set of limestones listed in Table 1 was used. However, the slowness of the diffusion process made it necessary to cut sections of drill core only 1–2 mm. thick so that the experiments could be completed within a reasonable time. Some concern was felt over the

reproducibility of such thin sections, but the experiments showed them to be surprisingly uniform.

plastic cylinder which in turn was mounted in the hole in the central partition of the cell with a cement identical in composition to the cell

TABLE 3.—DIFFUSION OF KCL THROUGH LIMESTONES

	Temp.	Original KCl conc.	KCl conc. on dilute side	Volume of solution on each compartment cm.³	ΔC_0	ΔC_f	Time	D	A'/l' Measured	Most prob.	Effective Directional Porosity
	°C.						*days*	*cm²/day*			
GREENHORN LS	*1*										
(Pfeifer)	25	0.9761 N	0.00	350							
Porosity = 34.0%	25		0.0078	350			0.99	1.73			
Permeability = 3 to	25		0.0157	340	0.9605	0.9447	0.93		1.72 a		
9 millidarcys	25		0.0245	335	0.9447	0.9271	0.93		1.81 b	1.75	10%
	25		0.0401	330	0.9271	0.8959	1.01		3.50* c		
	2										
	45	0.9948 N	0.00	400							
	45		0.0162	400			0.79	1.73			
	45		0.0331	395	0.9624	0.9286	0.85		4.75 d	4.8	29%
	45		0.0550	390	0.9286	0.8848	1.13		4.78 e		
	25		0.0707	385	0.8848	0.8534	1.00		4.02 f	4.0	24%
	25		0.0863	380	0.8534	0.8222	0.04		3.93 g		
	65		0.0835	370	0.8222	0.6278	2.00		14.5 h	14	84%
	65		0.2015	360	0.6278	0.4118	1.05		41.5* i		
OREAD LS	*3*										
(Leavenworth)	25	0.9948 N	0.00	400							
Porosity = 11.4%	25		0.0012	400			2.8	1.73			
Permeability = 0.007	25		0.0030	375	0.9924	0.9888	0.76		0.490 j		
to 0.01 millidarcys	25		0.0053	370	0.9888	0.9842	2.18		0.230 k		
	25		0.0063	365	0.9842	0.9822	0.99		0.220 l	0.23	3.1%
	25		0.0071	360	0.9822	0.9806	1.01		0.166 m		
	25		0.0082	355	0.9806	0.9724	1.01		0.234 n		
FORT RILEY LS	*4*										
Porosity = 18.2%	25	0.9988 N	0.00	400				1.73			
Permeability = 0.6 to	25		0.0041	400							
0.8 millidarcys	25		0.0086	395	0.9906	0.9816	1.33		0.79 o		
	25		0.0096	390	0.9816	0.9796	0.625		0.37 p	0.8	5%
	25		0.0141	385	0.9796	0.9706	1.20		0.87 q		

ΔC_0—difference in concentration between the two compartments at beginning of time interval.
ΔC_f—difference in concentration between the two compartments at end of time interval.
D—diffusion coefficient of KCl.
A'/l'—apparent ratio of core area to core length as measured by diffusion.
* Evaporation.

The experiments were conducted in a rectangular plastic cell divided into two square compartments by a vertical partition (Fig. 10). The sections of drill core were mounted in a

material. Temperature control was by immersion in a water bath controlled to 0.1°C. Prepared KCl solution and distilled water were poured simultaneously into the two compart-

ments, taking care to add exactly the same volume and to see that the cell was level and that the levels on the two sides of the partition were of equal height. This procedure eliminated the possibility of pressure flow of solution or water through the core and restricted the process to solute diffusion. A small pressure head existed because of the difference of density of the two solutions, but experiment proved that the pressure flow through the core because of the difference was entirely negligible. After a few hours, when a linear concentration gradient was assured and the cell had come to a uniform temperature, an analysis was made of the concentration of KCl in each compartment. Five milliliter samples were removed from each side with a pipette and titrated with standardized silver nitrate solution, using dichlorofluorescein as an indicator. The titrations were accurate to 1 or 2 parts in 1,000. After each run, the core and core holder were removed from the cell, and permanganate solution forced through the core assembly with air pressure. From the resulting color distribution in the core, it was possible to determine whether leaks had developed at the core boundary and also the exact area of core through which diffusion had taken place. On some cores, the cement penetrated the core a fraction of a millimeter, thus reducing somewhat the effective areas. In most cases, a 24-hour interval between determinations was sufficient to cause conveniently measureable concentration changes.

The data of the various runs are listed in Table 3.

Discussion

The A'/l' ratio.—The data of Table 3 can be used to obtain two important results—the A'/l' ratio and the quantity of solute delivered through a core under steady-state diffusion. The A'/l' ratio is the ratio of the effective area of the core to the effective pore length. The effective area is that part of the actual area of the core composed of pores through which diffusion takes place. It is the area of the single hole drilled through a completely impervious core to make it behave identically with the actual core. Since the intergranular pores are devious and irregular, they affect a diffusing salt as if they were straight, uniform tubes somewhat longer than the thickness of the core. This distance is the effective pore length, l'.

The ratio of A'/l' can be obtained by substituting in the equation:

$$A'/l' = \frac{V\left(\ln \frac{\Delta C_0}{\Delta C_f}\right)}{2D\Delta t} \qquad (11)$$

where V is the volume of solution in each compartment of the cell in cubic centimeters; ΔC_0 is the difference in concentration in equivalents per liter between the compartments at the beginning of the run; ΔC_f is the difference at the end of the run; D is the diffusion coefficient of the salt used, expressed in square centimeters per day; Δt is the time interval between the concentration measurements in days. The derivation of this equation is discussed at length by Gordon (1945).

Ideally only two measurements are necessary to determine A'/l', after a steady state is obtained, but a check can be made by a series of determinations. If the cell does not leak, if no evaporation occurs, if the solutions in both compartments are uniform at the time the samples are taken, if there is no density streaming through the cores, and, finally, if the cores are behaving as simple nonreacting non-adsorbing membranes, then successive determinations should give identical values of A'/l'.

The values listed for A'/l' in Table 3 show that the cores do act toward KCl as inert membranes. There are a number of anomalous values, but most of them can be explained on the basis of other variables.

In run #1, values *a* and *b* are quite close together, while *c* is much larger. This was undoubtedly due to evaporation, because the sum of the concentrations of the two compartments of the cell should equal the original concentration of the KCl used in the run. For runs *a* and *b* this sum was very close to the original, but for *c* the total was considerably higher.

In run #2 the values of A'/l' at 45° and at 25° checked well, but at 65° the values show a very marked increase from *h* to *i*. The concentration total at *h* was in good agreement with the required total, but that at *i* was far too great, suggesting evaporation loss again.

Three out of five values check on the #3 run, and two out of three are fairly close on the #4 run.

A scrutiny of all the experimental work led us to assign what we considered the most probable values.

USE OF A'/l' VALUES: Values of A'/l' form a most convenient measure of the effective directional porosity of the cores. When they are compared with the actual measured area and length, they can be used to define the per cent of the core which acts as a void in transmission of a diffusing non-reacting substance. For instance, the core used in run #2 had a measured cross-sectional area of 1.67 sq. cm., and a length of 0.10 cm. If we assume for convenience that the measured length of the core is the true pore length, then the effective area of transmission at 25° is:

$$\frac{A'}{l'} \times l = 4.0 \times 0.10 = 0.40 \text{ sq. cm.}$$

But the actual measured area of the core is 1.67 square cm. so the per cent effective directional porosity is:

$$\frac{0.40}{1.67} \times 100 = 24\%$$

Thus, if one wishes to calculate the amount of solute which will diffuse through any given cross section of the Greenhorn limestone with any given length, it is necessary only to reduce the actual rock area to its effective area, while continuing to use the actual length of the section through which the steady-state diffusion is to take place. The quantities of material which will diffuse through two rocks under the same conditions are in the ratios of their effective porosities.

Quantity of solute delivered through rocks.—After the A'/l' ratio is obtained, it is a simple matter to determine the quantity of solute which will pass through a given rock section. The general equation (Gordon, A. R. 1945) for this type of diffusion is:

$$\frac{dq}{dt} = D(C' - C'')A/l \qquad (12)$$

where q is the quantity of material in equivalents; t the time in days; D the diffusion coefficient of the particular substance or ion in square centimeters per day; C' the concentration on one side of the rock section in equivalents per cubic centimeter; C'' the concentration on the other; A the effective pore area in square centimeters; and l the length of the rock section in centimeters. For steady-state diffusion, in which C' remains constant and C'' is zero, the equation changes to:

$$q = \frac{DCtA}{l} \qquad (13)$$

The use of this equation is illustrated by the following problem: How many equivalents of KCl will diffuse in 1 year from a fissure containing 1.0 N KCl solution to a parallel fissure containing pure water, if the temperature is 25°C., the area of interest 1,000 sq. cm., and the distance between the fissures 25 cm.? Let us assume that the limestone in question is the Fort Riley limestone, with an effective directional porosity of 5 per cent. If so, then the effective area is $1{,}000 \times 0.05 = 20$ sq. cm. Substituting in #13 above:

$$q = \frac{1.73 \times 0.001 \times 365 \times 20}{25}$$

$$= 0.505 \text{ equivalents} = 37.6 \text{ grams}$$

In this problem, it is assumed that a steady state has been established before the beginning of the delivery. What if we wish to know the number of equivalents which will be delivered if we start with 1.0 N KCl in the fissure, but with the rock pores, as well as the second fissure, filled with pure water?

A good approximation of the time necessary for the establishment of the steady state can be made from the general equation for free diffusion. First we can calculate the time necessary for the 0.1 N concentration front to reach the second fissure. From the equation

$$\frac{C_0 - C}{2C_0} = \textit{Error Integral}\left[\frac{s}{\sqrt{2Dt}}\right]$$

we find that when

$$C = 0.01, \qquad \frac{s}{\sqrt{2Dt}} = 2.58 \text{ (Figure 7)}$$

Substituting $s = 25$ cm., and $D = 1.73$ sq. cm. per day, we find that $t = 27$ days. Nearly a

month will pass before any appreciable solute reaches the second fissure.

Next, we can approximate the time necessary to obtain a steady state by assuming that this time is approximated by the length of time necessary for a concentration front, equal to half the original concentration, to move by free diffusion to the midpoint between the two fissures. The basis for the approximation is that, in the steady state, the concentration gradient between the two fissures is linear and the concentration at the midpoint is 0.5 N.

From the general free diffusion equation # 10, when $C = 0.5$, $\frac{C_0 - C}{2C_0} = 0.25$, and $\frac{d}{\sqrt{2Dt}} = 0.68$, solving again for t we obtain:

$$t = 98 \text{ days}$$

Consequently, a steady state does not exist until 98 days have passed, and essentially no KCl reaches the second fissure until 27 days have elapsed. Under these revised conditions, the steady state lasts 365 − 98 = 267 days, with no delivery for 27 days. Making a liberal estimate that the amount delivered during the period of 98 − 27 = 71 days is 2/3 the amount in steady state, the quantity under the new conditions is the amount that would be delivered during

$$267 + 2/3 \times 71 = 314 \text{ days}$$

or, using the figures from the previous problem:

$$\text{amount in 314 days} = \frac{314}{365} \times 0.505$$
$$= 0.435 \text{ equivalents.}$$

Note that the amount delivered during steady state is directly proportional to the distance of transport. If the distance between fissures were 100 cm. instead of 25, the quantity of solute delivered in the same period of time would be a quarter as much. But the length of time necessary to establish the steady state increases much more rapidly. If the distance is 100 cm., the approximate time necessary for the steady state to ensue is 8400 days. As a matter of fact, the time necessary for the 0.01 front to reach the second fissure is 430 days.

Such calculations can be made for any salt or mixture of salts and for any rocks whose effective directional porosity has been determined. The great gap in our present knowledge is the temperature coefficient of the diffusion coefficient, although the values at 100°C. in Table 2 are of great help in assessing the order of magnitude to be expected.

Conclusion

The theory of diffusion as outlined should be useful in many geologic fields. It is hoped that enough sample problems have been given to make the specific procedure clear, and that the basic equation can be applied to any specific problems which might arise.

It is difficult to assess, even with the tools at hand, the importance of diffusion as a mechanism of material transfer until many specific problems are solved. Still, it is now worthwhile to summarize some of the salient features of the diffusion process. The amount of material which will pass through a rock by diffusion is essentially a linear function of the effective porosity; consequently there is a relatively small range in the amount which will diffuse through the most and least porous rocks, as opposed to the vastly greater range in the amount transferred by bodily movement of solution. In a sense, then, bodily permeability transfer is much more highly selective than diffusion transfer, and the relative importance of diffusion should be greater in rocks with small but numerous intergranular openings. Undoubtedly there is a marked decrease in diffusion through rocks with high porosity and extremely small grains, because of the increased surface effects. There was no indication of such a decrease in the limestones tested, but very different results might be expected with shales.

The few examples used show that significant quantities of material can be transferred over distances measured in feet within time intervals measured in tens of years, even at room temperature. Although many variables must be considered, this evidence should lift intergranular diffusion from the completely subsidiary role assigned to it by Bateman to a mechanism of importance. Certainly alteration zones several feet wide adjacent to veins might now be interpreted as entirely the result of solute diffusion.

It would be fascinating but dangerous to

speculate on diffusion effects at higher temperatures. It is better simply to bewail the lack of information on diffusion coefficients at elevated temperatures and pressures. If they were known, the first approximation could be made as to the effectiveness of intergranular diffusion in large-scale rock alteration and replacement.

The diaphragm cell data which have been presented are very scant at elevated temperatures, even under 100°C. Additional data are badly needed, both to ascertain the temperature coefficient of the diffusion coefficient and to determine the change in porosity with temperature. Our attention was focused entirely on the increase in quantity of material diffused as a function of temperature; no attempt was made to find out how much of the effect was due to an increase in D and how much to an actual increase in porosity resulting from grain expansion.

There are exciting possibilities of applying diffusion theory to problems of ionic segregation as a result of differing rates of movement of individual ions in salt mixtures. Is it possible to produce an acid "front" by diffusion an originally neutral solution through a few feet of nonreactive rock? "Solution differentiation" may be an important earth process.

Summary

1. Experimental work on diffusion through rock pores has been performed, and the results shown to be in accord with general diffusion theory.

2. The variables which control diffusion have been discussed, and the general equation $\frac{C_0 - C}{2C_0} = \textit{Error Integral}\left[\frac{s}{\sqrt{2Dt}}\right]$ has been shown to apply to the rate of penetration of diffusion fronts through rocks.

3. Values of D (diffusion coefficient) for simple salts, for individual "freed" ions, and for individual ions in salt mixtures have been listed, or the basis for their calculation shown.

4. The rate of penetration of a concentration front *through the limestones tested* is independent of porosity or permeability.

5. The amounts of material which diffuse through two rocks under comparable conditions are in the ratio of their effective directional porosities. Methods of determining these porosities are given.

6. An estimate of the *maximum* distance of penetration in 1,000,000 years of an effective concentration front of any ion into any rock at 100°C. gives a value of approximately 2½ miles. This calculation assumes movement of H^+ from a concentrated solution of constant composition with the proper salts present to give the H^+ maximum speed.

References Cited

Bateman, Alan (1942) *Economic Mineral Deposits*, John Wiley & Sons, New York.

Bowen, N. L. (1921) *Diffusion in Silicate Melts*, Jour. Geol., vol. 29, p. 295–717.

Brown, John S. (1947) *Porosity and ore deposits at Edwards and Balmat, New York*, Geol. Soc. Am., Bull., vol. 58, p. 536–537.

Duffel, Stanley (1937) *Diffusion and its relation to ore deposition*, Econ. Geol., vol. 32, p. 493–511.

Gordon, A. R. (1945) *The diaphragm cell method of studying diffusion*, N. Y. Acad. Sci., Ann., vol. 46, p. 285–308.

Cf. Handbook of Chemistry and Physics (1947) 30th Ed., p. 204–208.

Taylor, H. S. (1924) *Treatise on Physical Chemistry*, vol. 2, p. 939.

Vinograd, J. R. and McBain, J. W. (1941) *Diffusion of electrolytes and of their mixtures*, Am. Chem. Soc., Jour., vol. 63, p. 2008–2015.

Weissenberger, Arnold (Ed.) (1945) *Physical Methods of Organic Chemistry*, Interscience Publishers, Inc., vol. 1, p. 293–294, New York.

Wilke, E. and Strathmeyer, W. (1926) *Experimentelle Beitrage zur Theorie der Diffusionsvorgange*, Zeitschrift für Physik, vol. 40, p. 309–321.

Northwestern University, Evanston, Ill.; University of Kansas, Lawrence, Kansas; North Western University, Evanston, Ill.

Manuscript Received by the Secretary of the Society, November 22, 1948.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL 60, PP. 1829-1836, 5 PLS., 1 FIG. DECEMBER 1949

TERRAIN DIAGRAMS OF THE PHILIPPINE ISLANDS

BY PHILIP B. KING AND EDITH M. MCKEE

CONTENTS

	Page
Abstract	1829
Introduction	1829
Terrain diagrams	1830
Preparation of Philippine diagrams	1830
Geologic and tectonic features of Philippine Islands	1832
Geologic and tectonic sketch map	1832
Rock formations	1832
General statement	1832
Pre-Tertiary basement rocks	1832
Tertiary sedimentary rocks	1832
Tertiary volcanic rocks	1833
Quaternary sedimentary rocks	1833
Quarternary volcanic rocks	1833
Tectonic features	1833
General characteristics	1833
Features of northeast trend	1833
Philippine fault zone	1834
Mindanao Trench	1834
References cited	1835

ILLUSTRATIONS

Figure	Page
1. Index map of Philippine Islands showing areas covered by the four terrain diagrams, plates 1 to 4, and the nature of the source material used in compiling them	1831

Plate	Facing page
1. Terrain diagram of Luzon and the Visayan Islands, by Philip B. King	1830
2. Terrain diagram of Mindanao, by Philip B. King	1832
3. Terrain diagram of Palawan, by Edith M. McKee	1832
4. Terrain diagram of Sulu Archipelago, by Edith M. McKee	1834
5. Geologic and tectonic sketch map of Philippine Islands, compiled by Philip B. King	1834

ABSTRACT

This paper presents four terrain diagrams, on a scale of 1:1,000,000, which cover all the Philippine Islands. The diagrams were prepared during World War II by the Military Geology Unit of the U. S. Geological Survey for the Chief of Engineers, U. S. Army. Terrain features shown on the diagrams owe their individuality to the nature of the rock formations and the tectonics. Mountain areas are made up of pre-Tertiary basement rocks, and of Tertiary and Quaternary volcanics; Tertiary and Quaternary sediments from the lowland areas. The mountain areas of basement rocks are geanticlines or horsts, and the lowland areas of Tertiary sedimentary rocks are downwarps. A striking tectonic feature, which has strongly influenced the terrain, is the Philippine fault zone, a belt of dislocation which extends southeast from Luzon to Mindanao.

INTRODUCTION

This paper presents four terrain diagrams of Philippine Islands which were prepared during World War II by the Military Geology Unit of the U. S. Geological Survey for the Chief of Engineers, U. S. Army. The diagrams were intended for use in staff planning and for other military purposes at a time (1944) when the islands were still in the hands of the Japanese, and before the reoccupation of the islands by American forces. Besides the temporary military value of the diagrams, they have a more permanent value to geographers, geologists, and others, as a portrayal of the terrain of the islands. Arrangements have therefore been made with the Chief of Engineers to release them for civilian use.

The four terrain diagrams (Pls. 1–4) are all on a scale of 1:1,000,000, or 15.78 miles to the inch, and cover the whole Archipelago, as shown on Figure 1. The diagrams are reprinted without revision, in the form in which they were originally prepared. The diagrams of Luzon and the Visayan Islands (Pl. 1) and of Mindanao (Pl. 2) were prepared by Philip B. King. The diagrams of Palawan (Pl. 3) and the Sulu Archipelago (Pl. 4) were prepared by Edith M.

McKee. At the time the work was done, both King and McKee were members of the staff of the Military Geology Unit.

Terrain Diagrams

Terrain diagrams, also called physiographic diagrams, are graphic representations of physical features of the earth's surface. They resemble maps, and more particularly hachure maps. They differ from ordinary maps in that relief is artificially distorted to show it with an appearance of perspective. Also, various pictorial means are used to suggest the qualitative as well as the quantitative character of the terrain. Unlike an ordinary atlas or reference map, cultural features are subordinated to physical features. Towns and lines of communication are largely omitted, whereas mountains, scarps, valleys, swamps, and peculiarities of drainage are shown in considerable detail.

In preparing a terrain diagram, the diagrammist starts from a map base. Features near sea level, such as coasts and lowland rivers, are shown on the same positions on the diagram as on a map. However, mountain peaks and ridges are distorted from their true geographic form by being shifted toward the top of the map according to a predetermined scale—in the Philippine diagrams, the shift is $\frac{1}{10}$ inch for each 3,000 feet of altitude. Carried to its logical limit, this method would necessitate wholesale retracing of contours and other features, shifted out of true geographic position according to altitude. Ordinarily, such laborious methods are unnecessary; the diagrammist scales up selected spot heights and fills in the intervening area by free sketching. This distortion of relief, if carried out in detail, gives rise to a false but rather realistic appearance of perspective, as though the whole country were viewed from above, but at an angle of about 45°.

Preparation of Philippine Diagrams

The four terrain diagrams (Pls. 1–4) originally accompanied folio reports on different parts of the Philippine Islands that were prepared by the Military Geology Unit. The folios contained maps and text setting forth the geographic and geologic features of the area from a military standpoint. They were prepared by "teams", or co-ordinated groups of 5 or 10 geologists and other specialists. The teams spent much time searching for and assembling all possible source material, published, unpublished, and oral. By preparing the diagrams at the same time as a team was working on an area, the diagrammist had access to an unusually large file of source material.

A paragraph of text on each diagram indicates the principal sources used in preparing it. The quality of this source material and the areas covered by it are also shown on the index map of the islands (Fig. 1). On this map, the source material is divided into four groups, designated by the letters A to D. These groups and the sources comprising them are as follows:

A) Detailed topographic maps, large scales, good to excellent representation of terrain by means of contours:

1) Military survey of Luzon; 1:63,360.
2) Progressive military map of Philippine Islands:
   Rio Mindanao Valley, Cotabato, and Zamboanga areas in Mindanao, 1:62,500.
3) Surveys by National Development Company:
   Cebu, northwest Leyte, northeast Mindanao, 1:31,680 to 1:125,000; in manuscript.

B) Topographic maps, medium scales, fair representation of terrain by sketch contours, including small unsurveyed areas.

1) Surveys by National Development Company:
   Cagayan valley, Bicol and Bontoc peninsulas in Luzon; also in Panay, Cebu, and Masbate; various scales; in manuscript.
2) Military and forest surveys, Mindanao; various scales; partly in manuscript.

C) Coast surveys by U. S. Coast and Geodetic Survey. Detailed representation of coastal and offshore features. Terrain in narrow to broad strip of hinterland shown by contours or hachures, spot heights inland; quality of representation of terrain varied. Scales 1:20,000 to 1:200,000.

D) Compiled or exploratory maps, on small scales, with poor representation of terrain by hachures, in places including large unsurveyed areas.

1) Philippine Coast and Geodetic Survey maps of the different islands. Political divisions, towns, roads, and drainage in considerable detail, terrain by crude hachures.

19°
120°
121°
122°
123°
18°
17°
16°
C H I N A
S E A
BABUYAN CHANNEL
FUGA ISLAND
CAMIGUIN ISLAND
PALAUI ISLAND
Mayraira Pt.
Cape Bojeador
Cape Engaño
Escarpada Point
Aparri
LAOAG
LAOAG RIVER
Mt. Nagdubaduban
Mt. Lambayo
Mt. Cagua
Mt. Sicapoo
Mt. Burnay
Mt. Wayan
Mt. Cetacep
Mt. Marmanoc
Mt. Lobi
Vigan
Bantued
Tuguegarao
Mt. Dos Cuernos
Mt. Sapocoy
Mt. Muskut
Lubuagan
Divilacan Bay
Mt. Cresta
Mt. Alchan
Mt. Tangoe
Aubarede Point
Ilagan
Mt. Palanan
Palanan Point
Bontoc
Mt. Amuyao
Mt. Kapiligan
Mt. Lobo
Mt. Pulog
San Fernando
Dayombong
Mt. Dos Hermanos
SANTIAGO I.
Cape Bolinao
LINGAYEN
Baguio
Mt. Sto. Tomas
Diapitan Bay
CABARRUYAN I.
GULF
Lingayen
Casiguran Sound
Cape San Ildefonso
Caiman Pt.
Dasol Bay
Mt. Mangantarem
San Quintin
San Jose
Baler Bay
Baler
Cape Encanto
L U Z O N
P A
N

123° 124° 125° 126°

19°

18°

17°

16°

10 0 10 20 30 40 50 Statute Miles

10 0 10 20 30 40 50 60 70 Kilometers

EXPLANATION

Railroads (all narrow gauge, 3' 6")

Lakes

Swamps

Coral reefs (some sand banks included)

Sand banks and submerged mud flats

100 fathom submarine contour

Terrain diagram drawn on map base, A.M.S. 5301, Sheets NC 51, ND 51, and NE 51, 1:1,000,000. Details sketched from U.S. Coast and Geodetic Survey Charts, 1:100,000 to 1:200,000; Philippine Coast and Geodetic Survey maps 3-17, 1:200,000; Military Survey of Luzon, A. M. S. S711, 1:63,360; and from geologic and topographic maps of National Development Company, various scales. Altitudes in feet above sea level. Summits of hills and ridges are offset about 1/10 inch northward for each 3000 feet of altitude above sea level to give the impression of relief. Horizontal distances can be scaled only between points of equal altitude.

P A C I F I C

17°
16°
15°
14°
Bontoc
7015
Mt. Amuyao
8865
Ilagan
Mt. Palanan
Palanan Point
Mt. Kapilagan
Mt. Lobo
8586
Mt. Pulog
9613
San Fernando
Baguio
Mt. Sto. Tomas
SANTIAGO I.
LINGAYEN
GULF
CABARRUYAN I.
Cape Bolinao
Bayombong
Mt. Dos Hermanos
Diapitan Bay
Lingayen
San Quintin
Mt. Mangantarem
Cainlan Pt.
Dasol Bay
Casiguran Sound
Cape San Ildefonso
Baler Bay
Baler
Cape Encanto
San Jose
Tarlac
Cabanatuan
Dingalan Bay
Mt. Arayat
Candaba swamp
San Fernando
POLILLO ISLANDS
POLILLO
UALA ISLANDS
PATNANONGAN ISLAND
POLILLO ISLAND
JOMALIG ISLAND
Burdeos Bay
STRAIT
Malolos
Mt. Natib
Sampaloc Point
Subic Bay
Balanga
MANILA BAY
MANILA
Pasay
Pasig
Montalban
Mariveles Mts.
Mt. Bataan
Cavite
Cochinos Point
CORREGIDOR ISLAND
Naic
Elev. 7'
LAGUNA BAY
Santa Cruz
CALAGUA ISLANDS
LAMON BAY
BALESIN ISLAND
CABALETE ISLAND
Dapdap Point
ALABAT ISLAND
Mt. Cadig
Mt. Labo
3092
Daet
Calauag Bay
Lopez Bay
Mt. Banahao
Mt. Batulao
LAKE TAAL
Elev. 6'
Lucena
CABRA ISLAND
AMBIL ISLAND
LUBANG ISLAND
GOLA ISLAND
LUBANG ISLANDS
Balayan Bay
Cape Santiago
Balangas
TAYABAS BAY
Bantigui Point
MARICABAN ISLAND
VERDE ISLAND PASSAGE
Malabrigo Point
VERDE ISLAND
Mt. Colayiw
SAN MIGUEL BAY
Mt. Isarog
6182
Naga
RAGAY
QUINALA ISLAN
PHILIPPINE SEA

nt

P A C I F I C

17°

16°

O C E A N

S

15°

CALAGUA ISLANDS

814

2579

Daet

Mt. Labo
3092

2460

SAN MIGUEL
BAY

656

QUINALASAG
ISLAND

1383

1480

Mt. Isarog
6182

Naga

A Y

Yog Point

1081

2506

2110

CATANDUANES ISLAND

2330

Maqueda Channel

14°

POLILLO ISLANDS
POLILLO
ALA ISLANDS
PATNANONGAN ISLAND
POLILLO ISLAND
JOMALIG ISLAND
Burdeos Bay
STRAIT
San Fernando
swamp
Majolos
Mt. Natib 4422
Sampaloc Point
Subic Bay
Balanga
MANILA BAY
MANILA
Pasay
Pasig
Montelibano
Mt. Bataan 4666
Mariveles Mts.
Cavite
Cochinos Point
CORREGIDOR ISLAND
Naic
Elev. 7'
LAGUNA DE BAY
Santa Cruz
LAMON BAY
CALAGUA ISLANDS
BALESIN ISLAND
CABALETE ISLAND
Dapdap Point
ALABAT ISLAND
Calauag Bay
Mt. Cadig 2386
Daet
Mt. Labo 3092
Lopez Bay
Mt. Banahao
Mt. Batulao
TAAL LAKE
Elev. 8'
Lucena
QUINALASAG ISLAND
Yog Point
CABRA ISLAND
AMBIL ISLAND
LUBANG ISLAND
LUBANG ISLANDS
GOLA ISLAND
Balayan Bay
Cape Santiago
Balangas
TAYABAS BAY
Bantigui Point
SAN MIGUEL BAY
RAGAY GULF
Mt. Isarog 6182
Naga
Maqueda Channel
CATANDUANES ISLAND
Virac Point
MARICABAN ISLAND
VERDE ISLAND PASSAGE
Malabrigo Point
VERDE ISLAND
LAGONOY GULF
Mt. Calavite 4990
Cape Calavite
Calapan
Boac
Mt. San Antonio 2859
MARINDUQUE ISLAND
Mt. Malinao 5079
Lake Bato
Mayon Volcano 7943
Paluan Bay
Mt. Halcon 8481
BATAN ISLAND
RAPURAPU ISLAND
ALBAY GULF
Legaspi
Lake Naujan
Dumali Point
Bondoc Point
Bingay Point
Sorsogon
Sorsogon Bay
DOS HERMANAS ISLANDS
MINDORO
Mt. Baco 8160
MAESTRE DE CAMPO ISLAND
BANTON ISLAND
BURIAS ISLAND
Bulusan Volcano 5115
SIMARA ISLAND
SIBUYAN
Aguja Point
San Bernardino Strait
BALICUATRO ISLANDS
Dongon Point
APO ISLAND
Bugui Point
ROMBLON ISLAND
Romblon
TICAO ISLAND
DALUPIRIT ISLAND
CAPUL ISLAND
Mt. Guitinguitin 6750
SIBUYAN ISLAND
TABLAS ISLAND
Masbate
NARANJO ISLANDS
Pandan Point
Coconongon Point
BUSUANGA ISLAND
CALAMIAN GROUP
ILIN ISLAND
SEMIRARA ISLAND
CARABAO ISLAND
Pagbulungan Point
MASBATE
TAGAPULA ISLAND
Asid Gulf
SEMIRARA ISLANDS
CALUYA ISLAND
SIBAY ISLAND
Pulanduta Point
JINTOTOLO ISLAND
JINTOTOLO CHANNEL
Dumurug Point
ALMAGRO ISLAND
SANTO NINO ISLAND
MARIPIPI ISLAND
Caduruan Point
BILIRAN ISLAND
Coron Bay
CORON ISLAND
CULION ISLAND
Linapacan Strait
Pucio Point
Pandan Bay
Bulacaue Point
Pilar Bay
SIGANTE ISLANDS
VISAYAN
15°
14°
13°
12°

CALAGUA ISLANDS
814
2579
Daet
Mt. Labo
3097
2460
656
QUINALASAG ISLAND
SAN MIGUEL BAY
Mt. Isarog
6182
1480
Yog Point
1081
2506
2110
CATANDUANES ISLAND
2330
Maqueda Channel
Naga
1630
RIVER
392
Mt. Malinao
5079
Lake Bato
1590
Lake Buhi
Mayon Volcano
7943
BATAN ISLAND
RAPURAPU ISLAND
610
ALBAY GULF
Legaspi
3606
Bingay Point
530
BURIAS ISLAND
Sorsogon
855
Sorsogon Bay
1403
Bulusan Volcano
5115
2921
Aguja Point
Bugui Point
790
1330
TICAO ISLAND
837
2285
Masbate
790
Pagbulungan Point
390
1945
1422
1239
Asid Gulf
Pulanduta Point
JINTOTOLO ISLAND
JINTOTOLO CHANNEL
Pilar Bay
Bulacaue Point
GIGANTE ISLANDS
San Bernardino Strait
BALICUATRO ISLANDS
DALUPIRI ISLAND
832
CAPUL ISLAND
1617
NARANJO ISLANDS
TAGAPULA ISLAND
1410
Dumurug Point
1408
ALMAGRO ISLAND
1524
1550
SANTO NINO ISLAND
3320
MARIPIPI ISLAND
Caduruan Point
3630
BILIRAN ISLAND
4265
1258
DARAM ISLAND
LAOANG ISLAND
BATAG ISLAND
220
Cape Espiritu Santo
1363
1229
CATUBIG RIVER
Gomay Bay
ORAS RIVER
Bunga Point
Oras Bay
2319
Mt. Capotoan
2789
Mt. Canyapa
2620
1956
2759
ULUT RIVER
Carbalogan
1575
Mt. Yacgem
2198
Paninihian Point
15°
14°
13°
12°

TERRAIN DIAGRAM OF LUZO

By Ph

DIAGRAM OF LUZON AND THE VISAYAN ISLANDS

By Philip B. King

PREPARED BY U. S. GEOLOGICAL SURVEY
FOR
CHIEF OF ENGINEERS, U. S. ARMY

Luzon and Visayan Islands on 1:200,000, Mindanao on 1:600,000.

In addition to these sources, the diagrammists referred to written descriptions of the areas

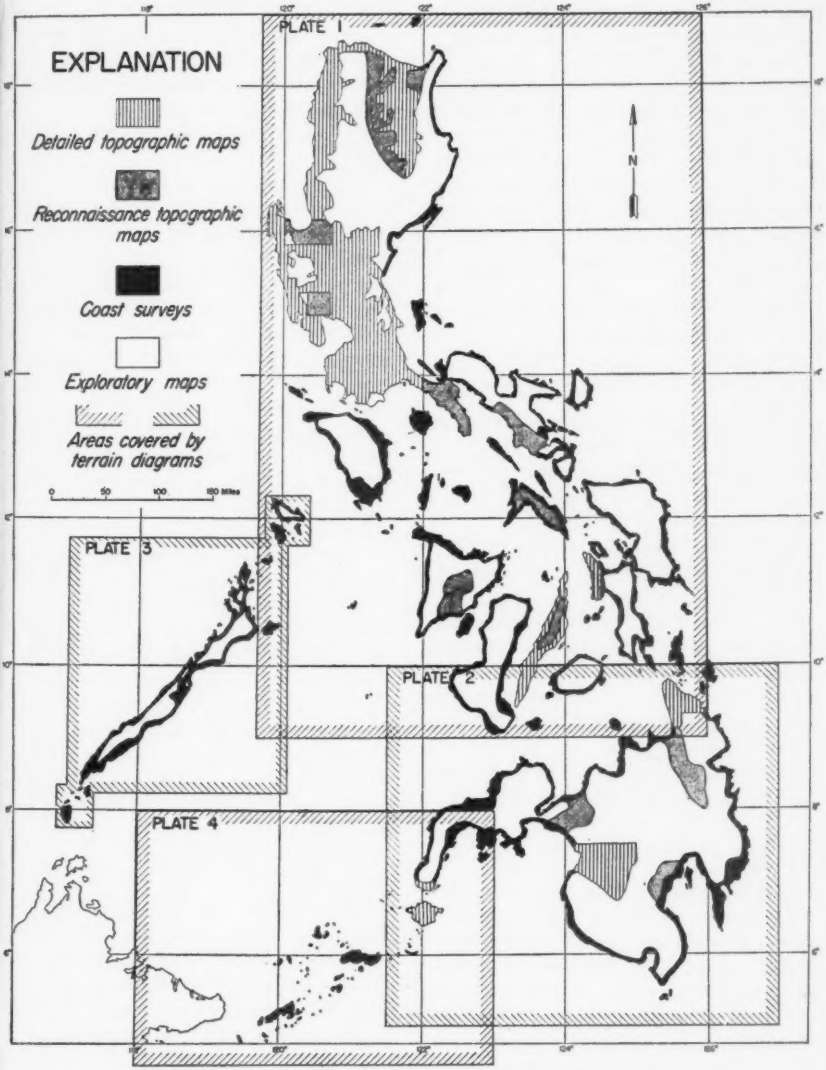


FIGURE 1.—INDEX MAP OF PHILIPPINE ISLANDS
Showing areas covered by the four terrain diagrams (Pls. 1–4) and the nature of the source material used in compiling them.

2) Miscellaneous military, geological, or forestry surveys, by sketch or exploratory methods; partly in manuscript.

and to geological reports. They also consulted with various specialists who had been in the islands, many of whom were on the staff of the

Military Geology Unit. These included F. M. Fryxell and R. D. Reed, who had made many geological surveys for the National Development Company, and R. L. Pendleton, who had made soil surveys in nearly all of the islands.

This descriptive, geological, and oral information was of great value for imparting qualative character to the terrain—for example, in determining whether a mountain peak was a young volcano, an old and dissected volcano, a ridge of folded sedimentary rock, or a massif of basement rock. Each of these would have a different form or appearance and would be shown differently on the diagram.

Geologic and Tectonic Features of Philippine Islands

Geologic and Tectonic Sketch Map

As the rock formations and tectonics have determined to a large extent the character of the terrain of the Philippine Islands, discussion of them should be an aid to appreciation of the features shown on the diagrams.

As a guide, a geologic and tectonic sketch map is included (Pl. 5). This has been compiled by King from published geologic maps (Smith, 1924, Pl. 39; Elicaño and Faustino, 1926; Willis, 1937, Pl. 2) and from information assembled by the Military Geology Unit. Submarine contours have been added from charts of the U. S. Hydrographic Office and U. S. Coast and Geodetic Survey. The map was drafted by Mrs. Marian Wheeler of the Office of Geologic Cartography, U. S. Geological Survey.

Rock Formations

General statement.—"The land areas of the Philippines are merely the higher portions of a submerged mountain mass, in part the crests of anticlinoria, in part the upthrust blocks or horsts caused by faulting, in part the summits of volcanoes" (Smith, 1924, p. 19). The rocks of the islands consist of a basement of pre-Tertiary age, of overlying Tertiary sedimentary and volcanic rocks, and of superficial Quaternary alluvium, marine deposits, and volcanics.

Pre-Tertiary basement rocks.—Basement rocks form the cores of the islands. They are of pre-Tertiary age, but for the most part their precise ages are unknown. In many of the island they include disturbed and partly metamor phosed sedimentary and pyroclastic rocks. O Mindoro and Cebu these have yielded fossil probably of Mesozoic age. For the most par the basement consists of plutonic rocks, chiefl of intermediate and basic composition. Ultra basic rocks, such as peridotites, now exten sively altered to serpentine, occur in many areas.

The basement rocks project as massifs, horsts, or geanticlines, which form some of the highest, most rugged and densely forested, and least accessible parts of the islands. They form the two high Cordilleras of northern Luzon where they culminate in Mt. Pulog (altitude 9613 feet), and the backbone of Mindoro of which Mt. Halcon (altitude 8481 feet) is the highest point. Somewhat lower but no less rugged areas of basement rocks form the western peninsula and eastern ranges of Mindanao. Smaller, narrower ridges, probably fault wedges, occur in southeastern Luzon and the eastern Visayan Islands.

Tertiary sedimentary rocks.—Unconformably on the basement are Tertiary sedimentary rocks. Extensive marine deposits consist of clastics and interbedded limestones. Other deposits are terrestrial and coal bearing. Pyroclastic rocks are present in many places. Rocks of Eocene and Oligocene age occur locally, but the main body is of Miocene and Pliocene age. The Tertiary sediments were deposited in downwarped areas between massifs or geanticlines of basement rocks and fill the downwarps to thicknesses of 15,000 to 30,000 feet. In the Cagayan Valley and Central Plain of Luzon, and the Iloilo Basin of Panay the surface form reflects the form of the original basin of deposition, although the beds are tilted on the flanks and locally folded. Elsewhere, as in the Bicol and Bontoc peninsula of southeast Luzon, and in Cebu, folding and erosion have destroyed the original form of the basins. In some areas where sedimentation has not been as great, as on Samar, the beds are little disturbed and form low plateaus.

In general, the Tertiary sedimentary rocks form foothills and lowlands. Some project as cuestas, hogbacks, and fold ridges, others as plateaus and table lands. Some of the most

122° 123° 124°

10

9

8

7

S U L U S E A

M I N D A N A O

NEGROS ISLAND

CEBU ISLAND

BOHOL ISLAND

SIQUIJOR ISLAND

Mt. Mambajao 5220

CAMIGUIN

Bagacay Point

Tagolo Point

Sulauan Point

MACAJALAR BAY

CAGAYAN

OROQUIETA

ILIGAN BAY

Mt. Ampiro 2530

Mt. Dapiak 8620

Mt. Malindang 7956

Port Misamis

MISAMIS

Sindangan Bay

Sindangan Point

AGUS RIVER

DANSALAN

CAGAYAN RIVER

Katanglad

Kalatungan

Gurain Mts.

Lake Lanao 2297

Mt. Iniaoan 5204

Mt. Ragang 9235

Mt. Piapayungan

BUTIG MTS.

Sugarloaf Mtn. 6030

Mt. Baga 1955

Mt. Silingar 2950

Dulunguin Point

Tupilac Pk. 2240

BUGUEY RIVER

L. Wood

SIBUGUEY BAY

Dumanquilas Bay

Baganian Peninsula

ILLANA BAY

VITALI ISLAND

OLUTANGA ISLAND

BONGO ISLAND

Polloc Hbr.

COTABATO

L. Labas

Libungan Marsh

MINDANAO RIVER

Mt. Blik 4021

Mt. Bingcay 3350

Liguasan Marsh

Lake Buluan

ZAMBOANGA

SACOL ISLAND

BASILAN STRAIT

PILAS GROUP

BASILAN

M O R O G U L F

124° 125° 126° 127°

BOHOL ISLAND
SIARGAO ISLAND
DINAGAT I.
Bilaa Point
SURIGAO
BUCAS GRANDE ISLAND
Lake Mainit
Lanuza Bay
Cauit Point
Mt. Mambajao
CAMIGUIN ISLAND
Diuata Point
BUTUAN BAY
Mt. Hilong-hilong
DIUATA MTS.
Bagacay Point
Gingoog Bay
BUTUAN
Mt. Malipay
Mt. Balatocan
Umanun Point
Mt. Diuata
Sulauan Point
MACAJALAR BAY
Mt. Amaloy
Lianga Bay
CAGAYAN
OROQUIETA
ILIGAN BAY
Lemon Point
Port Misamis
L. Lumago
Sanco Point
Katanglad Mts.
MALAYBALAY
DANSALAN
Gurain Mts.
Lake Lanao
Kalatungan Mts.
Mt. Ampaoid
Cateel Bay
Mt. Agtuuganon
Mt. Tangkulang
Mt. Ragang
Mt. Piapayungan
BUTIG MTS.
Bangai Point
Polloc Hbr.
Mt. Kampalili
BONGO ISLAND
COTABATO
L. Labas
Mt. Buluan
Libungan Marsh
Mt. Mayo
SAMAL I.
DAVAO
Mount Apo
Mt. Blik
Tugubun Point
Mt. Bintacan
Liguasan Marsh
TALIKUD I.
Mayo Bay
Paet Point
Mt. Libidan
Lamigan Point
Pujada Bay
Lake Buluan
DAVAO GULF
Colapsin Pt.

Sindangan Bay
Sindangan Point
Mt. Malindang 7956
Port Misamis
MISAMIS
AGUS RIVER
2047
2355
4035
Sugarloaf Mtn. 6030
Gurain Mts.
Lake 2297
Lanao
Mt. Iniaoan 5204
2060
2290
3400
Mt. Baga 1955
Mt. Silingar 2950
BUGUEY RIVER
855 L. Wood
Dulunguin Point
Tupilac Pk. 2240
7650
5497
2020
1952
2607
ILLANA
Baganian Peninsula
SIBUGUEY BAY
Dumanquilas Bay
1126
BAY
Polloc Hbr.
VITALI ISLAND
OLUTANGA ISLAND
BONGO ISLAND
4380
SACOL ISLAND
Mt. Bina Ca 3350
ZAMBOANGA
BASILAN STRAIT
MORO GULF
PILAS GROUP
BASILAN ISLAND
3317
TAPIANTANA GROUP
SAMALES GROUP

Terrain diagram drawn on map base, AMS5301, 1:1,000,000, sheets NC51, NC52, NB51, and NB52. Details added from Philippine Coast and Geodetic Survey Map 50, Mindanao, 1:600,000; from U.S. Coast and Geodetic Survey charts, 1:50,000 to 1:200,000; and from military, geological, and forest surveys. Data supplemental where possible from photographs, published descriptions, and oral accounts. Altitudes in feet above sea level.

Towns (only more important shown)

Main roads

Marsh or swamp (Fresh water marshes inland; mangrove swamps along coast

Lakes

Sandy beach

Submerged mud flats

Coral reefs (Includes some sand banks

100-fathom submarine contour

10 0 10 20 30 40 50 Miles

10 0 10 20 30 40 50 Kilometers

C E L E B E S S E

8 7 6 5

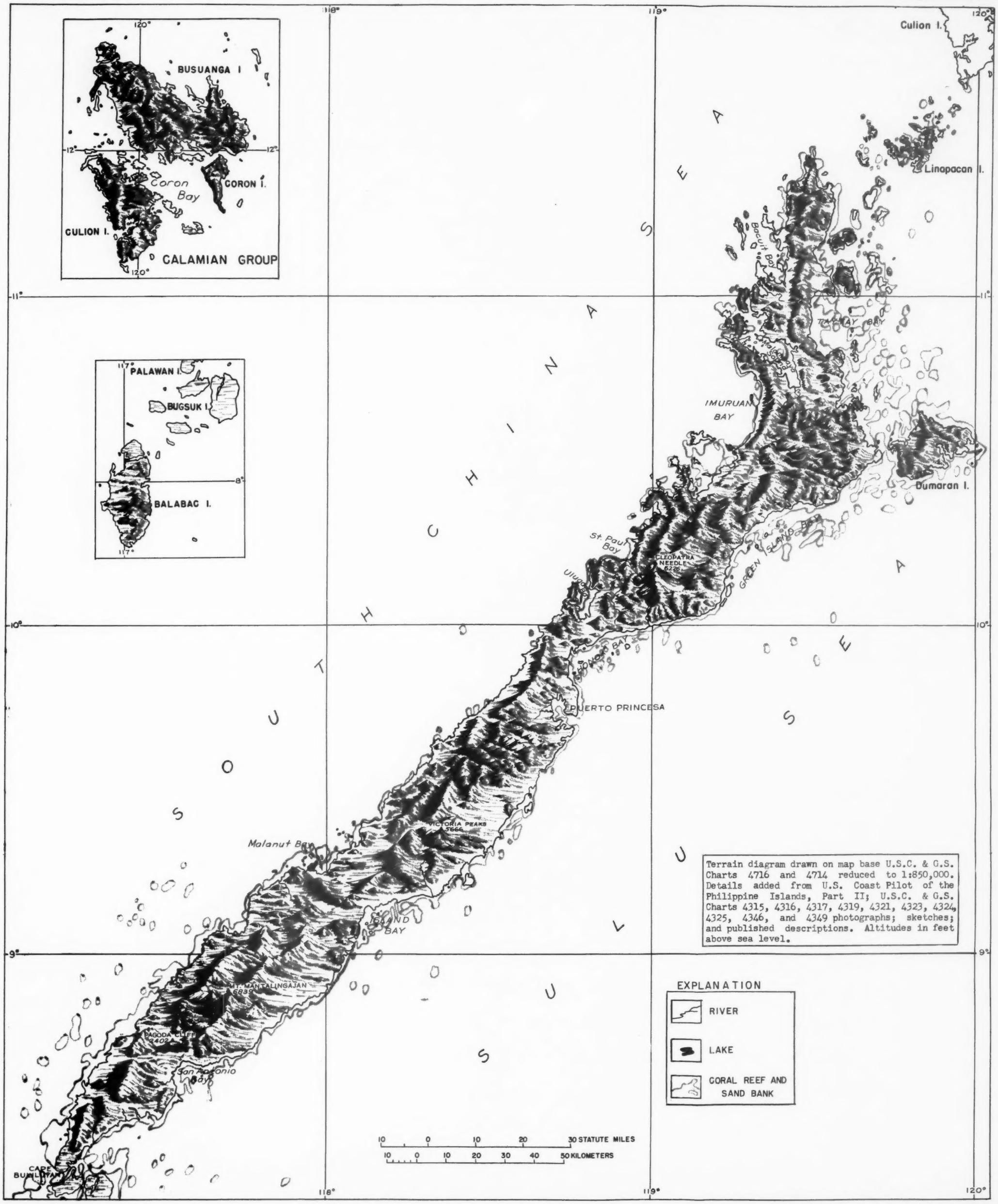
TERRAIN DIAGRAM

By Philip B.

RRAIN DIAGRAM OF MINDANAO

By Philip B. King

PREPARED BY U. S. GEOLOGICAL SURVEY
FOR
CHIEF OF ENGINEERS, U. S. ARMY


BUSUANGA I
CORON I.
Coron Bay
CULION I.
CALAMIAN GROUP
PALAWAN I.
BUGSUK I.
BALABAC I.
Culion I.
Linapacan I.
Bacuit Bay
TAYTAY BAY
IMURUAN BAY
Dumaran I.
St. Paul Bay
CLEOPATRA NEEDLE 6229
GREEN ISLAND BAY
ULUGAN BAY
PUERTO PRINCESA
VICTORIA PEAKS 5666
Malanut Bay
ISLAND BAY
MT. MANTALINGAJAN 6839
PAGODA CLIFF 2402
San Antonio Bay
CAPE BUNDUNGAN
SOUTH CHINA SEA
10 0 10 20 30 STATUTE MILES
10 0 10 20 30 40 50 KILOMETERS
Terrain diagram drawn on map base U.S.C. & G.S. Charts 4716 and 4714 reduced to 1:850,000. Details added from U.S. Coast Pilot of the Philippine Islands, Part II; U.S.C. & G.S. Charts 4315, 4316, 4317, 4319, 4321, 4323, 4324, 4325, 4346, and 4349 photographs; sketches; and published descriptions. Altitudes in feet above sea level.
EXPLANATION
RIVER
LAKE
CORAL REEF AND SAND BANK

TERRAIN DIAGRAM OF PALAWAN

By Edith M. McKee

PREPARED BY U. S. GEOLOGICAL SURVEY
FOR
CHIEF OF ENGINEERS, U. S. ARMY

prominent relief features are formed by limestone.

Tertiary volcanic rocks.—In many parts of the Philippines are volcanic rocks whose antiquity is indicated by dissection, by folding and faulting, or by hydrothermal alteration. These volcanics are more or less contemporaneous with the Tertiary sediments and probably belong to various epochs of the Tertiary. In general, they occur in positive areas between the sedimentary basins, and hence are adjacent to the areas of basement rocks. The most extensive areas of the older volcanics are in Mindanao.

The Tertiary volcanic rocks are greatly dissected by erosion so their original volcanic cones are either poorly preserved or are no longer recognizable. In part, the areas of Tertiary volcanics form plateaus or massifs only a little less rugged than the areas of basement rocks. Some of the massifs project from and are nearly engulfed by floods of younger volcanics.

Quaternary sedimentary rocks.—Quaternary sedimentary rocks form most of the plains of the Philippines. Here and there along the coasts are narrow coastal plains and small embayments floored by marine deposits and alluvium; elsewhere there are benches or terraces of uplifted coral reef rock. Inland, alluvial plains extend along some of the larger rivers or cover the lowest parts of the earlier Tertiary basins. The most extensive alluvial area is in the Central Plain of Luzon, between Manila and Lingayen Gulf, but other areas occur in the Cagayan valley of northern Luzon, and the Agusan valley, and valley of Rio Mindanao in Mindanao. Many of the plains contain lakes and marshy areas, resulting from ponding of drainage by alluviation or by crustal disturbance.

Quaternary volcanic rocks.—Quaternary volcanic rocks form great cones that dominate the landscape in many parts of the Philippines and include peripheral sheets of lava and tuff that extend out from the bases of the cones. The cones occur in chains, in clusters, or singly and are more common in the eastern than the western part of the islands. Although the Quaternary volcanics give rise to some of the most striking features of the Philippine landscape, their areal extent is considerably less than that of the Tertiary volcanics and Tertiary sediments amid which they lie.

Mount Apo in Mindanao, a dormant and somewhat dissected volcanic cone, is the highest peak in the Philippines (altitude 9690 feet) (Pl. 2); Mayon, a still-active volcano in southeastern Luzon, rises from water's edge to an altitude of 7943 feet and has a remarkably beautiful and symmetrical cone (Pl. 1). Taal, an active volcano in southern Luzon, has a low cone which projects from the middle of a wide lake, probably a caldera. Many of the islands of the Sulu Archipelago are formed by small basaltic cones (Pl. 4).

Tectonic Features

General characteristics.—The Philippine Islands lie in one of the mobile belts of the earth and have been unstable for a long period of geologic history. To an important extent, the features shown on the terrain diagrams are a product of tectonic activity.

Much yet remains to be learned regarding the tectonics of this part of the earth, but the main characters have been determined. The broader relations of the Philippines and the western Pacific to the east and northeast have been discussed by Hess (1948). Schuppli (1946, p. 5–12) has summarized the work of the Dutch geologists in the East Indies to the southwest. The tectonics of the Philippines themselves have been treated by various authors, including Becker (1901, p. 543–547), Sadena Masó and Smith (1913), and Willis (1937).

Features of northeast trend.—Becker and later authors have observed that the southwest part of the Philippine Islands is composed of topographic and geologic features of northeast trend. These give place in the eastern part of the islands to features of north-northwest or northwest trend, the line of junction extending from southeastern Luzon to eastern Mindanao. "The southwestern ranges seem to gather in toward the eastern edge of the Philippines as do the branches of a tree to its trunk" (Becker, 1901, p. 544). Features of the two directions join on Masbate, which "seems to be the keystone of the Philippine structure" (Sadena Masó and Smith, 1913, p. 207).

The general relations of the two trends are shown on Plate 5. Both trends appear in the

south part of the terrain diagram (Pl. 1), where the northeast system is shown by the ranges on Panay, Negros, and Cebu, and the northwest system by the ranges and islands between southeast Luzon and northeast Mindanao. Palawan, a fine example of the northeast trend, appears on Plate 3.

Features of northeast trend form topographic ridges, the ranges and cordilleras of the islands, separated by depressions, for the most part submerged beneath the sea. These have a tectonic as well as a topographic character. The ranges expose basement rocks along their crests and are therefore anticlinoria or upraised fault blocks. One of the depressions, in central Panay, is a synclinorium enclosing a thick mass of Tertiary sediments.

Philippine fault zone.—The line of junction between the northeast- and northwest-trending features of the Philippines is a great zone of dislocation, termed the Philippine fault zone by Willis (1937, p. 38–40) and others. Its general course is indicated on Plate 5 by a heavy line. No doubt the zone is broad, with many parallel, en echelon, and diverging fractures, but the details are so poorly known that it would be hazardous to attempt to show them. Details of the land forms along the fault zone are indicated on the terrain diagrams (Pls. 1, 2).

The fault zone is most strikingly shown in the land forms between Ragay Gulf, southeast Luzon, and northeast Mindanao. In this region there is a striking alinement of long, narrow uplands and lowlands, expressed as ridges and valleys on the land, and as islands and channels where partly submerged (Pl. 1). Many of these features are probably bounded by faults. To the south in Mindanao the fault zone follows Agusan Valley and Davao Gulf (Pl. 2), where numerous violent earthquakes have been recorded since 1870 (Sadena Masó and Smith, 1913, p. 213, 223).

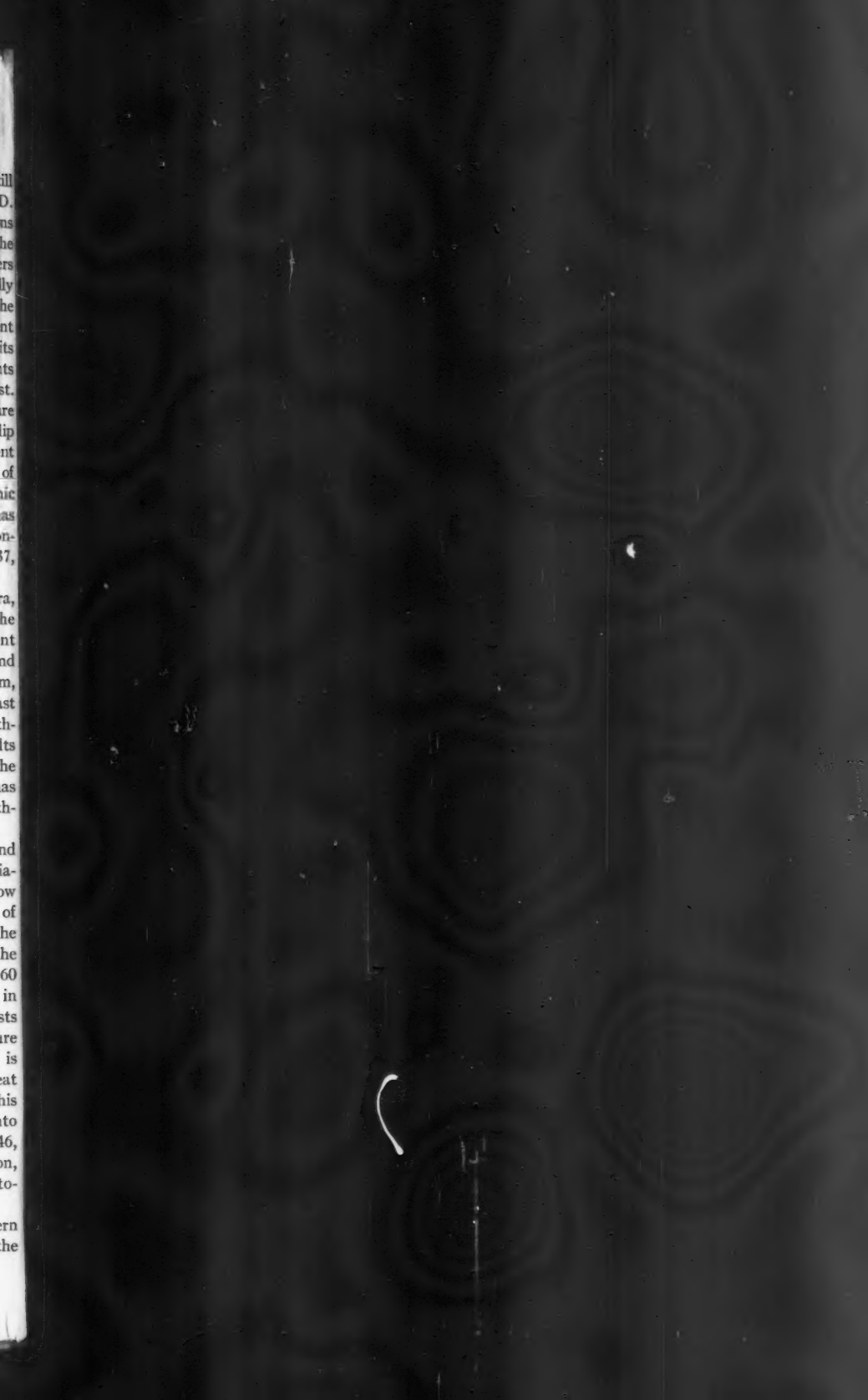
Northwestward, the fault zone has been traced with less certainty. The terrain diagram (Pl. 1) shows, along its projected course, a low gap in the eastern cordillera of Luzon at Dingalan Bay and, beyond, a scarp which separates the northern cordilleras of Luzon from the Central Plain. Willis (1937, p. 20–21) has expressed doubt that this scarp marks a continuation of the fault zone; he pointed out that the scarp consists of a number of offset parts, and that the whole is much eroded. Still farther northwest, near Lingayan Gulf, R. D. Reed has observed that Tertiary formations strike across the apparent extension of the fault zone, seemingly without offset. The writers suggest that the Philippine fault zone actually does lie along the course suggested by the terrain diagram, but that its displacement diminishes northwestward, that the fault splits into branches, and that the latest movements on it in this area are older than to the southeast.

Movements on the Philippine fault zone are probably mainly horizontal or in a strike-slip direction, and the fault is thus a transcurrent fault, comparable to the San Andreas fault of California. The regional plan of the tectonic features suggests that the southwest side has moved relatively southeast, a suggestion confirmed by outcrop observations by Willis (1937, p. 39) on Masbate.

It is interesting to note that in Sumatra, symmetrically placed on the opposite side of the East Indies arc, another large transcurrent fault has been reported, which may extend nearly the entire length of the island (Durham, 1940). On this, movement on the northeast side is believed to have been relatively southeast. Both the Philippine and Sumatra faults may be related to a southeastward surge of the crust of the East Indies arc, which thus has moved past the crustal segments to the northeast and southwest of it.

Mindanao Trench.—A major topographic and tectonic feature not shown on the terrain diagrams is the Mindanao Trench, a long narrow ocean deep that lies off the east coast of Mindanao and Samar. It is illustrated by the submarine contours on Plate 5. East of the northeast tip of Mindanao, depths of 5560 fathoms or 33,360 feet have been recorded in the trench. Hess (1948, p. 421, Pl. 1) suggests that the trench is not only a topographic feature of the ocean bottom, but that its course is followed by the axis of a "tectogene" or great down-buckle in the crust of the earth. This "tectogene" probably continues southward into the arc of the East Indies (Schuppli, 1946, p. 9, Fig. 2). Northwestward, east of Luzon, the Mindanao Trench fades out, and the "tectogene" probably fades out with it.

Many of the major structures of the eastern Philippines may be related to the growth of the



Scale 1:1,000,000

10 5 0 10 20 30 40 50 60 70 80 90 100 Miles

10 5 0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 Kilometers

10 5 0 10 20 30 40 50 60 70 Nautical Miles

118° 119° 120° 121°

8° 7° 6° 5°

SANDAKAN BAY

BORNEO

Lahad Datu

DARVEL BAY

SIBUTU I

PANGUTARAN I

Jolo

JOLO

TAWI TAWI I

SULU SEA

TERRAIN DIAGRAM OF SULU ARCHIPELAGO

By Edith M. McKee

121° 122° 123°

7°

6°

5°

Miles

SIBUGUEY BAY

Zamboanga

BASILAN I

PANGUTARAN I

Jolo

JOLO I

TAWI TAWI I

SULU SEA

Coral reefs. Swamps Roads (incompletely shown).

Terrain diagram on map base AMS 5301, sheets NB 50 and NB 51, scale of 1:1,000,000. Additional data from Philippine Coast and Geodetic Survey Map 50 (Mindanao 1:60,000), U.S.H.O. charts, views, and written descriptions. Altitudes in feet above sea level. Summits of hills and ridges are offset about 1/10 inch northward for each 3000 feet of altitude above sea level to give the impression of relief. Horizontal distances can be scaled only between points of equal altitude.

DIAGRAM OF SULU ARCHIPELAGO

By Edith M. McKee

PREPARED BY U. S. GEOLOGICAL SURVEY
FOR
CHIEF OF ENGINEERS, U. S. ARMY

Three out of five values check on the #3 run, and two out of three are fairly close on the #4 run.

A scrutiny of all the experimental work led us to assign what we considered the most probable values.

USE OF A'/l' VALUES: Values of A'/l' form a most convenient measure of the effective directional porosity of the cores. When they are compared with the actual measured area and length, they can be used to define the per cent of the core which acts as a void in transmission of a diffusing non-reacting substance. For instance, the core used in run #2 had a measured cross-sectional area of 1.67 sq. cm., and a length of 0.10 cm. If we assume for convenience that the measured length of the core is the true pore length, then the effective area of transmission at 25° is:

$$\frac{A'}{l'} \times l = 4.0 \times 0.10 = 0.40 \text{ sq. cm.}$$

But the actual measured area of the core is 1.67 square cm. so the per cent effective directional porosity is:

$$\frac{0.40}{1.67} \times 100 = 24\%$$

Thus, if one wishes to calculate the amount of solute which will diffuse through any given cross section of the Greenhorn limestone with any given length, it is necessary only to reduce the actual rock area to its effective area, while continuing to use the actual length of the section through which the steady-state diffusion is to take place. The quantities of material which will diffuse through two rocks under the same conditions are in the ratios of their effective porosities.

Quantity of solute delivered through rocks.—After the A'/l' ratio is obtained, it is a simple matter to determine the quantity of solute which will pass through a given rock section. The general equation (Gordon, A. R. 1945) for this type of diffusion is:

$$\frac{dq}{dt} = D(C' - C'')A/l \qquad (12)$$

where q is the quantity of material in equivalents; t the time in days; D the diffusion coefficient of the particular substance or ion in square centimeters per day; C' the concentration on one side of the rock section in equivalents per cubic centimeter; C'' the concentration on the other; A the effective pore area in square centimeters; and l the length of the rock section in centimeters. For steady-state diffusion, in which C' remains constant and C'' is zero, the equation changes to:

$$q = \frac{DC_0 A}{l} \qquad (13)$$

The use of this equation is illustrated by the following problem: How many equivalents of KCl will diffuse in 1 year from a fissure containing 1.0 N KCl solution to a parallel fissure containing pure water, if the temperature is 25°C., the area of interest 1,000 sq. cm., and the distance between the fissures 25 cm.? Let us assume that the limestone in question is the Fort Riley limestone, with an effective directional porosity of 5 per cent. If so, then the effective area is $1{,}000 \times 0.05 = 20$ sq. cm. Substituting in #13 above:

$$q = \frac{1.73 \times 0.001 \times 365 \times 20}{25}$$

$$= 0.505 \text{ equivalents} = 37.6 \text{ grams}$$

In this problem, it is assumed that a steady state has been established before the beginning of the delivery. What if we wish to know the number of equivalents which will be delivered if we start with 1.0 N KCl in the fissure, but with the rock pores, as well as the second fissure, filled with pure water?

A good approximation of the time necessary for the establishment of the steady state can be made from the general equation for free diffusion. First we can calculate the time necessary for the 0.1 N concentration front to reach the second fissure. From the equation

$$\frac{C_0 - C}{2C_0} = \textit{Error Integral}\left[\frac{s}{\sqrt{2Dt}}\right]$$

we find that when

$$C = 0.01, \qquad \frac{s}{\sqrt{2Dt}} = 2.58 \text{ (Figure 7)}$$

Substituting $s = 25$ cm., and $D = 1.73$ sq. cm. per day, we find that $t = 27$ days. Nearly a

...onth will pass before any appreciable solute ...aches the second fissure.

Next, we can approximate the time necessary ...o obtain a steady state by assuming that this ...me is approximated by the length of time ...ecessary for a concentration front, equal to ...alf the original concentration, to move by ...ee diffusion to the midpoint between the two ...issures. The basis for the approximation is ...hat, in the steady state, the concentration ...radient between the two fissures is linear and ...he concentration at the midpoint is 0.5 N.

From the general free diffusion equation # 10, when $C = 0.5$, $\frac{C_o - C}{2C_o} = 0.25$, and $\frac{d}{\sqrt{2Dt}} = 0.68$, solving again for t we obtain:

$$t = 98 \text{ days}$$

Consequently, a steady state does not exist until 98 days have passed, and essentially no KCl reaches the second fissure until 27 days have elapsed. Under these revised conditions, the steady state lasts $365 - 98 = 267$ days, with no delivery for 27 days. Making a liberal estimate that the amount delivered during the period of $98 - 27 = 71$ days is 2/3 the amount in steady state, the quantity under the new conditions is the amount that would be delivered during

$$267 + 2/3 \times 71 = 314 \text{ days}$$

or, using the figures from the previous problem:

$$\text{amount in 314 days} = \frac{314}{365} \times 0.505$$
$$= 0.435 \text{ equivalents.}$$

Note that the amount delivered during steady state is directly proportional to the distance of transport. If the distance between fissures were 100 cm. instead of 25, the quantity of solute delivered in the same period of time would be a quarter as much. But the length of time necessary to establish the steady state increases much more rapidly. If the distance is 100 cm., the approximate time necessary for the steady state to ensue is 8400 days. As a matter of fact, the time necessary for the 0.01 front to reach the second fissure is 430 days.

Such calculations can be made for any salt or mixture of salts and for any rocks whose effective directional porosity has been determined. The great gap in our present knowledge is the temperature coefficient of the diffusion coefficient, although the values at 100°C. in Table 2 are of great help in assessing the order of magnitude to be expected.

Conclusion

The theory of diffusion as outlined should be useful in many geologic fields. It is hoped that enough sample problems have been given to make the specific procedure clear, and that the basic equation can be applied to any specific problems which might arise.

It is difficult to assess, even with the tools at hand, the importance of diffusion as a mechanism of material transfer until many specific problems are solved. Still, it is now worthwhile to summarize some of the salient features of the diffusion process. The amount of material which will pass through a rock by diffusion is essentially a linear function of the effective porosity; consequently there is a relatively small range in the amount which will diffuse through the most and least porous rocks, as opposed to the vastly greater range in the amount transferred by bodily movement of solution. In a sense, then, bodily permeability transfer is much more highly selective than diffusion transfer, and the relative importance of diffusion should be greater in rocks with small but numerous intergranular openings. Undoubtedly there is a marked decrease in diffusion through rocks with high porosity and extremely small grains, because of the increased surface effects. There was no indication of such a decrease in the limestones tested, but very different results might be expected with shales.

The few examples used show that significant quantities of material can be transferred over distances measured in feet within time intervals measured in tens of years, even at room temperature. Although many variables must be considered, this evidence should lift intergranular diffusion from the completely subsidiary role assigned to it by Bateman to a mechanism of importance. Certainly alteration zones several feet wide adjacent to veins might now be interpreted as entirely the result of solute diffusion.

It would be fascinating but dangerous to

speculate on diffusion effects at higher temperatures. It is better simply to bewail the lack of information on diffusion coefficients at elevated temperatures and pressures. If they were known, the first approximation could be made as to the effectiveness of intergranular diffusion in large-scale rock alteration and replacement.

The diaphragm cell data which have been presented are very scant at elevated temperatures, even under 100°C. Additional data are badly needed, both to ascertain the temperature coefficient of the diffusion coefficient and to determine the change in porosity with temperature. Our attention was focused entirely on the increase in quantity of material diffused as a function of temperature; no attempt was made to find out how much of the effect was due to an increase in D and how much to an actual increase in porosity resulting from grain expansion.

There are exciting possibilities of applying diffusion theory to problems of ionic segregation as a result of differing rates of movement of individual ions in salt mixtures. Is it possible to produce an acid "front" by diffusion an originally neutral solution through a few feet of nonreactive rock? "Solution differentiation" may be an important earth process.

Summary

1. Experimental work on diffusion through rock pores has been performed, and the results shown to be in accord with general diffusion theory.

2. The variables which control diffusion have been discussed, and the general equation $\frac{C_0 - C}{2C_0} = \textit{Error Integral}\left[\frac{s}{\sqrt{2Dt}}\right]$ has been shown to apply to the rate of penetration of diffusion fronts through rocks.

3. Values of D (diffusion coefficient) for simple salts, for individual "freed" ions, and for individual ions in salt mixtures have been listed, or the basis for their calculation shown.

4. The rate of penetration of a concentration front *through the limestones tested* is independent of porosity or permeability.

5. The amounts of material which diffuse through two rocks under comparable conditions are in the ratio of their effective directional porosities. Methods of determining these porosities are given.

6. An estimate of the *maximum* distance of penetration in 1,000,000 years of an effective concentration front of any ion into any rock at 100°C. gives a value of approximately 2½ miles. This calculation assumes movement of H^+ from a concentrated solution of constant composition with the proper salts present to give the H^+ maximum speed.

References Cited

Bateman, Alan (1942) *Economic Mineral Deposits*, John Wiley & Sons, New York.

Bowen, N. L. (1921) *Diffusion in Silicate Melts*, Jour. Geol., vol. 29, p. 295–717.

Brown, John S. (1947) *Porosity and ore deposits at Edwards and Balmat, New York*, Geol. Soc. Am., Bull., vol. 58, p. 536–537.

Duffel, Stanley (1937) *Diffusion and its relation to ore deposition*, Econ. Geol., vol. 32, p. 493–511.

Gordon, A. R. (1945) *The diaphragm cell method of studying diffusion*, N. Y. Acad. Sci., Ann., vol. 46, p. 285–308.

Cf. Handbook of Chemistry and Physics (1947 30th Ed., p. 204–208.

Taylor, H. S. (1924) *Treatise on Physical Chemistry*, vol. 2, p. 939.

Vinograd, J. R. and McBain, J. W. (1941) *Diffusion of electrolytes and of their mixtures*, Am. Chem. Soc., Jour., vol. 63, p. 2008–2015.

Weissenberger, Arnold (Ed.) (1945) *Physical Methods of Organic Chemistry*, Interscience Publishers, Inc., vol. 1, p. 293–294, New York.

Wilke, E. and Strathmeyer, W. (1926) *Experimentelle Beitrage zur Theorie der Diffusionsvorgange*, Zeitschrift für Physik, vol. 40, p. 309–321.

Northwestern University, Evanston, Ill.
University of Kansas, Lawrence, Kansas.
North Western University, Evanston, Ill.

Manuscript Received by the Secretary of the Society, November 22, 1948.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 60, PP. 1829-1836, 5 PLS., 1 FIG. DECEMBER 1949

TERRAIN DIAGRAMS OF THE PHILIPPINE ISLANDS

BY PHILIP B. KING AND EDITH M. MCKEE

CONTENTS

	Page
Abstract	1829
Introduction	1829
Terrain diagrams	1830
Preparation of Philippine diagrams	1830
Geologic and tectonic features of Philippine Islands	1832
Geologic and tectonic sketch map	1832
Rock formations	1832
General statement	1832
Pre-Tertiary basement rocks	1832
Tertiary sedimentary rocks	1832
Tertiary volcanic rocks	1833
Quaternary sedimentary rocks	1833
Quarternary volcanic rocks	1833
Tectonic features	1833
General characteristics	1833
Features of northeast trend	1833
Philippine fault zone	1834
Mindanao Trench	1834
References cited	1835

ILLUSTRATIONS

Figure	Page
1. Index map of Philippine Islands showing areas covered by the four terrain diagrams, plates 1 to 4, and the nature of the source material used in compiling them	1831

Plate	Facing page
1. Terrain diagram of Luzon and the Visayan Islands, by Philip B. King	1830
2. Terrain diagram of Mindanao, by Philip B. King	1832
3. Terrain diagram of Palawan, by Edith M. McKee	1832
4. Terrain diagram of Sulu Archipelago, by Edith M. McKee	1834
5. Geologic and tectonic sketch map of Philippine Islands, compiled by Philip B. King	1834

ABSTRACT

This paper presents four terrain diagrams, on a scale of 1:1,000,000, which cover all the Philippine Islands. The diagrams were prepared during World War II by the Military Geology Unit of the U. S. Geological Survey for the Chief of Engineers, U. S. Army. Terrain features shown on the diagrams owe their individuality to the nature of the rock formations and the tectonics. Mountain areas are made up of pre-Tertiary basement rocks, and of Tertiary and Quaternary volcanics; Tertiary and Quaternary sediments from the lowland areas. The mountain areas of basement rocks are geanticlines or horsts, and the lowland areas of Tertiary sedimentary rocks are downwarps. A striking tectonic feature, which has strongly influenced the terrain, is the Philippine fault zone, a belt of dislocation which extends southeast from Luzon to Mindanao.

INTRODUCTION

This paper presents four terrain diagrams of the Philippine Islands which were prepared during World War II by the Military Geology Unit of the U. S. Geological Survey for the Chief of Engineers, U. S. Army. The diagrams were intended for use in staff planning and for other military purposes at a time (1944) when the islands were still in the hands of the Japanese, and before the reoccupation of the islands by American forces. Besides the temporary military value of the diagrams, they have a more permanent value to geographers, geologists, and others, as a portrayal of the terrain of the islands. Arrangements have therefore been made with the Chief of Engineers to release them for civilian use.

The four terrain diagrams (Pls. 1–4) are all on a scale of 1:1,000,000, or 15.78 miles to the inch, and cover the whole Archipelago, as shown on Figure 1. The diagrams are reprinted without revision, in the form in which they were originally prepared. The diagrams of Luzon and the Visayan Islands (Pl. 1) and of Mindanao (Pl. 2) were prepared by Philip B. King. The diagrams of Palawan (Pl. 3) and the Sulu Archipelago (Pl. 4) were prepared by Edith M.

McKee. At the time the work was done, both King and McKee were members of the staff of the Military Geology Unit.

Terrain Diagrams

Terrain diagrams, also called physiographic diagrams, are graphic representations of physical features of the earth's surface. They resemble maps, and more particularly hachure maps. They differ from ordinary maps in that relief is artificially distorted to show it with an appearance of perspective. Also, various pictorial means are used to suggest the qualitative as well as the quantitative character of the terrain. Unlike an ordinary atlas or reference map, cultural features are subordinated to physical features. Towns and lines of communication are largely omitted, whereas mountains, scarps, valleys, swamps, and peculiarities of drainage are shown in considerable detail.

In preparing a terrain diagram, the diagrammist starts from a map base. Features near sea level, such as coasts and lowland rivers, are shown on the same positions on the diagram as on a map. However, mountain peaks and ridges are distorted from their true geographic form by being shifted toward the top of the map according to a predetermined scale—in the Philippine diagrams, the shift is $\frac{1}{10}$ inch for each 3,000 feet of altitude. Carried to its logical limit, this method would necessitate wholesale retracing of contours and other features, shifted out of true geographic position according to altitude. Ordinarily, such laborious methods are unnecessary; the diagrammist scales up selected spot heights and fills in the intervening area by free sketching. This distortion of relief, if carried out in detail, gives rise to a false but rather realistic appearance of perspective, as though the whole country were viewed from above, but at an angle of about 45°.

Preparation of Philippine Diagrams

The four terrain diagrams (Pls. 1–4) originally accompanied folio reports on different parts of the Philippine Islands that were prepared by the Military Geology Unit. The folios contained maps and text setting forth the geographic and geologic features of the area from a military standpoint. They were prepared by "teams", or co-ordinated groups of 5 or 10 geologists and other specialists. The teams spent much time searching for and assembling all possible source material, published, unpublished, and oral. By preparing the diagrams at the same time as a team was working on an area, the diagrammist had access to an unusually large file of source material.

A paragraph of text on each diagram indicates the principal sources used in preparing it. The quality of this source material and the areas covered by it are also shown on the index map of the islands (Fig. 1). On this map, the source material is divided into four groups, designated by the letters A to D. These groups and the sources comprising them are as follows:

A) Detailed topographic maps, large scales, good to excellent representation of terrain by means of contours:

1) Military survey of Luzon; 1:63,360.
2) Progressive military map of Philippine Islands:
   Rio Mindanao Valley, Cotabato, and Zamboanga areas in Mindanao, 1:62,500.
3) Surveys by National Development Company:
   Cebu, northwest Leyte, northeast Mindanao, 1:31,680 to 1:125,000; in manuscript.

B) Topographic maps, medium scales, fair representation of terrain by sketch contours, including small unsurveyed areas.

1) Surveys by National Development Company:
   Cagayan valley, Bicol and Bontoc peninsulas in Luzon; also in Panay, Cebu, and Masbate; various scales; in manuscript.
2) Military and forest surveys, Mindanao; various scales; partly in manuscript.

C) Coast surveys by U. S. Coast and Geodetic Survey. Detailed representation of coastal and offshore features. Terrain in narrow to broad strip of hinterland shown by contours or hachures, spot heights inland; quality of representation of terrain varied. Scales 1:20,000 to 1:200,000.

D) Compiled or exploratory maps, on small scales, with poor representation of terrain by hachures, in places including large unsurveyed areas.

1) Philippine Coast and Geodetic Survey maps of the different islands. Political divisions, towns, roads, and drainage in considerable detail, terrain by crude hachures.

Luzon and Visayan Islands on 1:200,000, Mindanao on 1:600,000.

In addition to these sources, the diagrammists referred to written descriptions of the areas

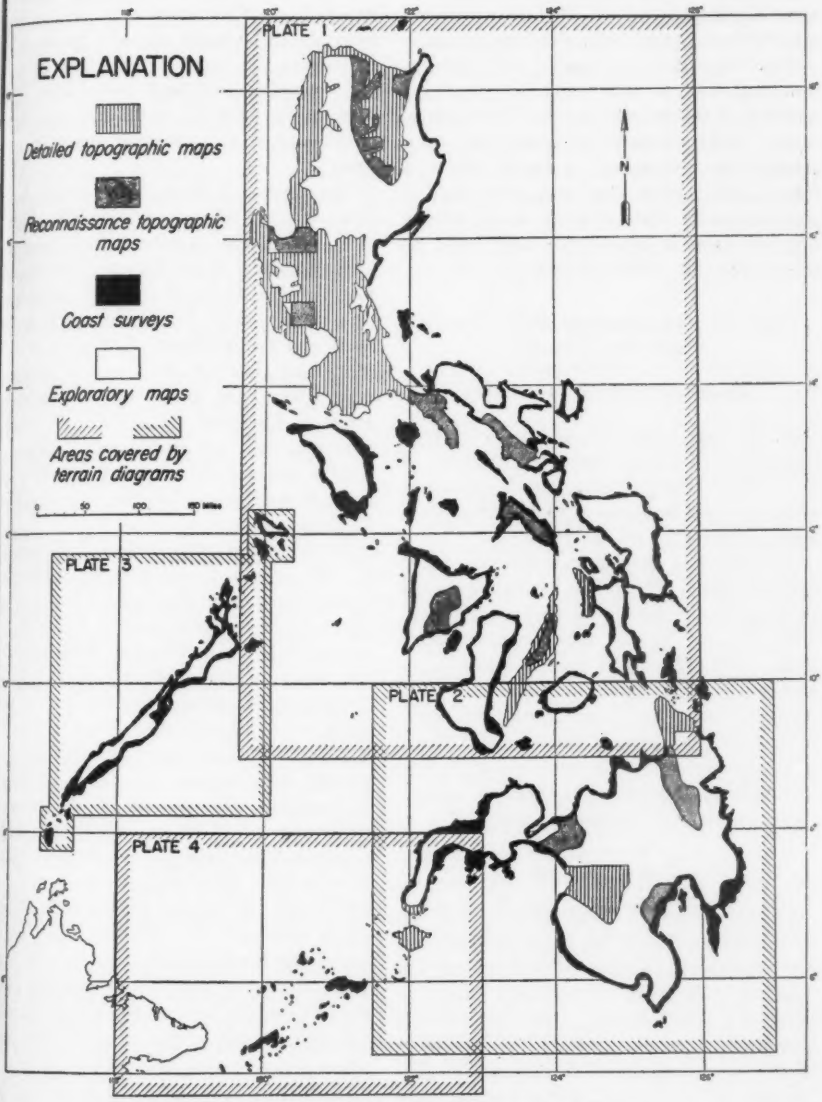


FIGURE 1.—INDEX MAP OF PHILIPPINE ISLANDS
Showing areas covered by the four terrain diagrams (Pls. 1–4) and the nature of the source material used in compiling them.

2) Miscellaneous military, geological, or forestry surveys, by sketch or exploratory methods; partly in manuscript.

and to geological reports. They also consulted with various specialists who had been in the islands, many of whom were on the staff of the

Military Geology Unit. These included F. M. Fryxell and R. D. Reed, who had made many geological surveys for the National Development Company, and R. L. Pendleton, who had made soil surveys in nearly all of the islands.

This descriptive, geological, and oral information was of great value for imparting qualative character to the terrain—for example, in determining whether a mountain peak was a young volcano, an old and dissected volcano, a ridge of folded sedimentary rock, or a massif of basement rock. Each of these would have a different form or appearance and would be shown differently on the diagram.

Geologic and Tectonic Features of Philippine Islands

Geologic and Tectonic Sketch Map

As the rock formations and tectonics have determined to a large extent the character of the terrain of the Philippine Islands, discussion of them should be an aid to appreciation of the features shown on the diagrams.

As a guide, a geologic and tectonic sketch map is included (Pl. 5). This has been compiled by King from published geologic maps (Smith, 1924, Pl. 39; Elicaño and Faustino, 1926; Willis, 1937, Pl. 2) and from information assembled by the Military Geology Unit. Submarine contours have been added from charts of the U. S. Hydrographic Office and U. S. Coast and Geodetic Survey. The map was drafted by Mrs. Marian Wheeler of the Office of Geologic Cartography, U. S. Geological Survey.

Rock Formations

General statement.—"The land areas of the Philippines are merely the higher portions of a submerged mountain mass, in part the crests of anticlinoria, in part the upthrust blocks or horsts caused by faulting, in part the summits of volcanoes" (Smith, 1924, p. 19). The rocks of the islands consist of a basement of pre-Tertiary age, of overlying Tertiary sedimentary and volcanic rocks, and of superficial Quaternary alluvium, marine deposits, and volcanics.

Pre-Tertiary basement rocks.—Basement rocks form the cores of the islands. They are of pre-Tertiary age, but for the most part their precise ages are unknown. In many of the isla they include disturbed and partly metam phosed sedimentary and pyroclastic rocks. Mindoro and Cebu these have yielded fos probably of Mesozoic age. For the most p the basement consists of plutonic rocks, chi of intermediate and basic composition. Ul basic rocks, such as peridotites, now ext sively altered to serpentine, occur in ma areas.

The basement rocks project as massifs, hor or geanticlines, which form some of the high most rugged and densely forested, and l accessible parts of the islands. They form two high Cordilleras of northern Luzon wh they culminate in Mt. Pulog (altitude 9 feet), and the backbone of Mindoro of wh Mt. Halcon (altitude 8481 feet) is the hig point. Somewhat lower but no less rug areas of basement rocks form the west peninsula and eastern ranges of Minda Smaller, narrower ridges, probably fault wed occur in southeastern Luzon and the east Visayan Islands.

Tertiary sedimentary rocks.—Unconforma on the basement are Tertiary sediment rocks. Extensive marine deposits consist of c tics and interbedded limestones. Other depo are terrestrial and coal bearing. Pyroclastic ro are present in many places. Rocks of Eoc and Oligocene age occur locally, but the ma body is of Miocene and Pliocene age. T Tertiary sediments were deposited in do warped areas between massifs or geanticli of basement rocks and fill the downwarps thicknesses of 15,000 to 30,000 feet. In Cagayan Valley and Central Plain of Luz and the Iloilo Basin of Panay the surface fo reflects the form of the original basin of de sition, although the beds are tilted on t flanks and locally folded. Elsewhere, as in t Bicol and Bontoc peninsula of southeast Luz and in Cebu, folding and erosion have destroy the original form of the basins. In some are where sedimentation has not been as great, on Samar, the beds are little disturbed and for low plateaus.

In general, the Tertiary sedimentary roc form foothills and lowlands. Some project cuestas, hogbacks, and fold ridges, others plateaus and table lands. Some of the m

minent relief features are formed by lime-
ne.

Tertiary volcanic rocks.—In many parts of
Philippines are volcanic rocks whose antiq-
y is indicated by dissection, by folding and
lting, or by hydrothermal alteration. These
lcanics are more or less contemporaneous
th the Tertiary sediments and probably be-
ng to various epochs of the Tertiary. In
neral, they occur in positive areas between the
dimentary basins, and hence are adjacent to
e areas of basement rocks. The most extensive
eas of the older volcanics are in Mindanao.
The Tertiary volcanic rocks are greatly dis-
ected by erosion so their original volcanic
nes are either poorly preserved or are no
nger recognizable. In part, the areas of Terti-
y volcanics form plateaus or massifs only a
tle less rugged than the areas of basement
cks. Some of the massifs project from and
e nearly engulfed by floods of younger vol-
nics.

Quaternary sedimentary rocks.—Quaternary
dimentary rocks form most of the plains of
e Philippines. Here and there along the
asts are narrow coastal plains and small
ibayments floored by marine deposits and
luvium; elsewhere there are benches or ter-
ces of uplifted coral reef rock. Inland, allu-
ial plains extend along some of the larger
vers or cover the lowest parts of the earlier
ertiary basins. The most extensive alluvial
ea is in the Central Plain of Luzon, between
anila and Lingayen Gulf, but other areas
cur in the Cagayan valley of northern Luzon,
d the Agusan valley, and valley of Rio
indanao in Mindanao. Many of the plains
ntain lakes and marshy areas, resulting from
nding of drainage by alluviation or by crustal
sturbance.

Quaternary volcanic rocks.—Quaternary vol-
nic rocks form great cones that dominate
e landscape in many parts of the Philippines
d include peripheral sheets of lava and tuff
at extend out from the bases of the cones.
he cones occur in chains, in clusters, or singly
d are more common in the eastern than the
estern part of the islands. Although the
uaternary volcanics give rise to some of the
ost striking features of the Philippine land-
ape, their areal extent is considerably less
than that of the Tertiary volcanics and Tertiary sediments amid which they lie.

Mount Apo in Mindanao, a dormant and somewhat dissected volcanic cone, is the highest peak in the Philippines (altitude 9690 feet) (Pl. 2); Mayon, a still-active volcano in southeastern Luzon, rises from water's edge to an altitude of 7943 feet and has a remarkably beautiful and symmetrical cone (Pl. 1). Taal, an active volcano in southern Luzon, has a low cone which projects from the middle of a wide lake, probably a caldera. Many of the islands of the Sulu Archipelago are formed by small basaltic cones (Pl. 4).

Tectonic Features

General characteristics.—The Philippine Islands lie in one of the mobile belts of the earth and have been unstable for a long period of geologic history. To an important extent, the features shown on the terrain diagrams are a product of tectonic activity.

Much yet remains to be learned regarding the tectonics of this part of the earth, but the main characters have been determined. The broader relations of the Philippines and the western Pacific to the east and northeast have been discussed by Hess (1948). Schuppli (1946, p. 5–12) has summarized the work of the Dutch geologists in the East Indies to the southwest. The tectonics of the Philippines themselves have been treated by various authors, including Becker (1901, p. 543–547), Sadena Masó and Smith (1913), and Willis (1937).

Features of northeast trend.—Becker and later authors have observed that the southwest part of the Philippine Islands is composed of topographic and geologic features of northeast trend. These give place in the eastern part of the islands to features of north-northwest or northwest trend, the line of junction extending from southeastern Luzon to eastern Mindanao. "The southwestern ranges seem to gather in toward the eastern edge of the Philippines as do the branches of a tree to its trunk" (Becker, 1901, p. 544). Features of the two directions join on Masbate, which "seems to be the keystone of the Philippine structure" (Sadena Masó and Smith, 1913, p. 207).

The general relations of the two trends are shown on Plate 5. Both trends appear in the

south part of the terrain diagram (Pl. 1), where the northeast system is shown by the ranges on Panay, Negros, and Cebu, and the northwest system by the ranges and islands between southeast Luzon and northeast Mindanao. Palawan, a fine example of the northeast trend, appears on Plate 3.

Features of northeast trend form topographic ridges, the ranges and cordilleras of the islands, separated by depressions, for the most part submerged beneath the sea. These have a tectonic as well as a topographic character. The ranges expose basement rocks along their crests and are therefore anticlinoria or upraised fault blocks. One of the depressions, in central Panay, is a synclinorium enclosing a thick mass of Tertiary sediments.

Philippine fault zone.—The line of junction between the northeast- and northwest-trending features of the Philippines is a great zone of dislocation, termed the Philippine fault zone by Willis (1937, p. 38–40) and others. Its general course is indicated on Plate 5 by a heavy line. No doubt the zone is broad, with many parallel, en echelon, and diverging fractures, but the details are so poorly known that it would be hazardous to attempt to show them. Details of the land forms along the fault zone are indicated on the terrain diagrams (Pls. 1, 2).

The fault zone is most strikingly shown in the land forms between Ragay Gulf, southeast Luzon, and northeast Mindanao. In this region there is a striking alinement of long, narrow uplands and lowlands, expressed as ridges and valleys on the land, and as islands and channels where partly submerged (Pl. 1). Many of these features are probably bounded by faults. To the south in Mindanao the fault zone follows Agusan Valley and Davao Gulf (Pl. 2), where numerous violent earthquakes have been recorded since 1870 (Sadena Masó and Smith, 1913, p. 213, 223).

Northwestward, the fault zone has been traced with less certainty. The terrain diagram (Pl. 1) shows, along its projected course, a low gap in the eastern cordillera of Luzon at Dingalan Bay and, beyond, a scarp which separates the northern cordilleras of Luzon from the Central Plain. Willis (1937, p. 20–21) has expressed doubt that this scarp marks a continuation of the fault zone; he pointed out that the scarp consists of a number of offset parts, and that the whole is much eroded. So farther northwest, near Lingayan Gulf, R. Reed has observed that Tertiary formation strike across the apparent extension of t fault zone, seemingly without offset. The write suggest that the Philippine fault zone actual does lie along the course suggested by t terrain diagram, but that its displacement diminishes northwestward, that the fault spli into branches, and that the latest movemen on it in this area are older than to the southea

Movements on the Philippine fault zone a probably mainly horizontal or in a strike-sli direction, and the fault is thus a transcurre fault, comparable to the San Andreas fault California. The regional plan of the tecton features suggests that the southwest side h moved relatively southeast, a suggestion con firmed by outcrop observations by Willis (193 p. 39) on Masbate.

It is interesting to note that in Sumatra symmetrically placed on the opposite side of th East Indies arc, another large transcurren fault has been reported, which may exten nearly the entire length of the island (Durhan 1940). On this, movement on the northeas side is believed to have been relatively south east. Both the Philippine and Sumatra fault may be related to a southeastward surge of th crust of the East Indies arc, which thus ha moved past the crustal segments to the north east and southwest of it.

Mindanao Trench.—A major topographic and tectonic feature not shown on the terrain diagrams is the Mindanao Trench, a long narrow ocean deep that lies off the east coast of Mindanao and Samar. It is illustrated by the submarine contours on Plate 5. East of the northeast tip of Mindanao, depths of 5560 fathoms or 33,360 feet have been recorded in the trench. Hess (1948, p. 421, Pl. 1) suggests that the trench is not only a topographic feature of the ocean bottom, but that its course is followed by the axis of a "tectogene" or great down-buckle in the crust of the earth. This "tectogene" probably continues southward into the arc of the East Indies (Schuppli, 1946, p. 9, Fig. 2). Northwestward, east of Luzon, the Mindanao Trench fades out, and the "tectogene" probably fades out with it.

Many of the major structures of the eastern Philippines may be related to the growth of the

tectogene" of the Mindanao Trench and the ast Indies arc. The ultrabasic plutonic rocks hich are a prominent feature of the basement ocks of the eastern Philippines may be related o an early stage of its development (Hess, 1948, . 432–433). Later stages may be indicated by he Philippine fault zone, by belts of seismic ctivity, and by belts of volcanism. Much yet emains to be learned regarding the history of he "tectogene" which follows the Mindanao rench. Hess (1948, p. 433) suggests that it may ave taken form toward the end of Mesozoic ime, but the continuation of tectonic, volcanic, nd seismic activity near it in the eastern hilippines through Tertiary and Quaternary ime suggests that its growth has continued to this day.

References Cited

Becker, G. F. (1901) *Report on the geology of the Philippine Islands*, U. S. Geol. Survey, 21st Ann. Rept. (1899–1900), vol. 3, p. 493–614.

Durham, J. W. (1940) *Oeloe Aer fault zone, Sumatra*, Am. Assoc. Petrol. Geol., Bull., vol. 24, p. 359–362.

Elicaño, Victoriano, and Faustino, L. A. (1926) *Preliminary geologic map of the Philippine Islands*, Div. Geol. Mines, Philippine Bur. Sci.

Hess, H. H. (1948) *Major structural features of the western north Pacific: an interpretation of H. O. 5485, bathymetric chart, Korea to New Guinea*, Geol. Soc. Am., Bull., vol. 59, p. 417–446.

Sadena Masó, Miguel, and Smith, W. D. (1913) *The relation of seismic disturbances in the Philippines to the geologic structure*, Philippine Jour. Sci., vol. 8, p. 199–232.

Schuppli, H. M. (1946) *Oil basins of East Indian archipelago*, Am. Assoc. Petrol. Geol., Bull., vol. 30, p. 1–22.

Smith, W. D. (1924) *Geology and mineral resources of the Philippine Islands*, Philippine Bur. Sci.

Willis, Bailey (1937) *Geologic observations in the Philippine archipelago*, Philippine Islands Nat. Research Council, Bull. 13.

U. S. Geological Survey, Gatlinburg, Tenn.; Arabian-American Oil Company, Dhahran, Saudi Arabia

Manuscript Received by the Secretary of the Society, July 27, 1949

Published with Permission of the Director, Geological Survey, U. S. Department of Interior

SEISM

Abstract. . .
Introductio
Determina
Tonga-Ker

Figure
1. Strain-
Ker
km.)
2. Strain-
Ker
480 k
3. Tonga-
geste
sequ
4. Tonga-
deep
5. Sketch
grea

Table
1. Tonga-K
2. Tonga-K
680 k
3. South A
km.) .

A meth
lastic-rebo
arthquak
given sequ
cumulated
time repre
the interva
also provi
nt a cho
novement
it becomes
wise may
s offered v
and Soutl
originate
imental m
km. and

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 60, PP. 1837-1856, 10 FIGS. DECEMBER 1949

SEISMIC EVIDENCE FOR THE FAULT ORIGIN OF OCEANIC DEEPS

BY HUGO BENIOFF

CONTENTS

	Page		Page
Abstract	1837	South American earthquake sequences	1846
Introduction	1837	Other deep-focus sequences	1855
Determination of strain-rebound increments	1838	Tsunamis and the great faults	1855
Tonga-Kermadec earthquake sequences	1841	References cited	1856

ILLUSTRATIONS

Figure	Page	Figure	Page
1. Strain-rebound increments of the Tonga-Kermadec shallow sequence ($h < 70$ km.)	1842	6. Strain-rebound increments of the South American shallow sequence ($h < 70$ km.)	1852
2. Strain-rebound increments of the Tonga-Kermadec deep sequence ($h = 70 - 480$ km.	1843	7. Strain-rebound increments of the South American intermediate sequence ($h = 70 - 300$ km.)	1853
3. Tonga-Kermadec fault mechanism suggested by strain-rebound curve of deep sequence	1843	8. Strain-rebound increments of the South American deep sequence ($h = 550 - 660$ km.)	1853
4. Tonga-Kermadec earthquakes and oceanic deeps	1844	9. South American earthquakes and oceanic deeps	1854
5. Sketch illustrating proposed origin of the great Tonga-Kermadec fault	1845	10. Sketch illustrating proposed origin of the great South American fault	1855

TABLES

Table	Page	Table	Page
1. Tonga-Kermadec shallow sequence	1839	4. South American intermediate sequence ($h = 70 - 300$ km.)	1849
2. Tonga-Kermadec deep sequence ($h = 70 - 680$ km.)	1840	5. South American deep sequence ($h = 550 - 660$ km.)	1851
3. South American shallow sequence ($h < 70$ km.)	1847		

ABSTRACT

A method is described for determining the elastic-rebound strain increments associated with earthquakes occurring on a particular fault. For a given sequence of earthquakes, a graph of the accumulated increments so determined plotted against time represents the actual fault movement during the interval covered by the sequence. The method also provides a means for determining whether or not a chosen sequence of earthquakes represents movements of a single fault structure. In this way it becomes possible to discover faults which otherwise may escape detection. Evidence of this kind is offered which indicates that the Tonga-Kermadec and South American sequences of earthquakes originate on great faults which dip under the continental masses. The faults are approximately 2500 km. and 4500 km. in length respectively. Their transverse dimensions are approximately 900 km. each. They both extend to a depth of approximately 650 km.—more than one tenth of the radius of the earth. The oceanic deeps associated with these faults are surface expressions of the downwarping of their oceanic blocks. The upwarping of their continental blocks have produced islands in the Tonga-Kermadec region and the Andes Mountains in South America.

INTRODUCTION

In another paper in preparation the writer develops a method for deriving numbers proportional to the elastic-rebound strain increments associated with individual earthquakes on a given fault. The method depends upon the instrumental earthquake magnitude scale

of Richter (1935) as revised by Gutenberg and Richter (1942). In a study of a number of aftershock sequences it has yielded information as to the strain activity of fault rocks during the time intervals in which aftershocks occurred. The strain characteristics so determined are in close agreement with the creep-recovery characteristics of rocks as measured in the laboratory. It was thus possible to demonstrate with reasonable certainty that aftershocks are produced by elastic afterworking of the fault rocks. The method has been applied to a study of sequences of earthquakes, other than aftershocks, originating in a number of active seismic regions. If the earthquakes of a given sequence are generated by strain-relief increments on a single fault, a graph of the accumulated increments plotted against time represents the actual intermittent motion of the fault blocks. The method thus makes it possible to observe tectonic processes in action. It may serve also to determine whether or not a given sequence of earthquakes is derived from movements of a single fault structure and so, in effect, to establish the existence of a fault which may have otherwise escaped detection. The discovery of two great faults from evidence of this kind is presented.

Determination of Strain-Rebound Increments

It will be of help to review briefly the procedure for deriving elastic strain-rebound increments from earthquake magnitudes. If an average elastic strain ϵ_1 preceding an earthquake is assumed to be distributed uniformly throughout an effective volume V of the *fault rock*, the strain energy stored in the rock is given by the equation:

$$E = \tfrac{1}{2}\mu V\epsilon_1^2. \qquad \text{ergs} \ldots\ldots (1)$$

where μ is the appropriate elastic constant of the rock. When the fault slips to produce the earthquake, a fraction p of the stored elastic energy is converted into seismic waves. Thus if J is the energy of the waves,

$$J = \tfrac{1}{2}P\mu V\epsilon_1^2. \qquad \text{ergs} \ldots\ldots (2)$$

For a given fault μ and V are constants. Moreover it is reasonable to assume that p is also constant and very nearly equal to unity. Hence equation (2) may be written

$$J = C^2\epsilon_1^2. \qquad \text{ergs} \ldots\ldots (3)$$

where C is a constant such that

$$C^2 = \tfrac{1}{2}p\mu V.$$

If the strain is reduced to zero during the earthquake the stored elastic strain is equal to the strain rebound,
that is

$$\epsilon_1 = \epsilon$$

Hence

$$J = C^2\epsilon^2 \qquad \text{ergs} \ldots\ldots (4)$$

Taking the square root of equation (4),

$$J^{\frac{1}{2}} = C\epsilon \qquad (\text{ergs})^{\frac{1}{2}} \ldots (5)$$

Thus on a given fault the square root of the energy of an earthquake is proportional to the *elastic-strain rebound increment* which generates it. The fault-rebound displacement x corresponding with the strain-rebound increment is given by

$$x = m\epsilon$$

where m is a constant depending upon the size and shape of the volume V of strained rock. Hence

$$J^{\frac{1}{2}} = kx \qquad \ldots\ldots\ldots (6)$$

where $k = mC$. The square root of the earthquake energy is thus proportional to the rebound displacement also. If S is the accumulated sum of the values of $J^{\frac{1}{2}}$ for a sequence of earthquakes derived from a single fault, a graph of S versus time represents the fault displacement (multiplied by the undetermined constant k) or the strain relief (multiplied by C) as a function of time. Values for $J^{\frac{1}{2}}$ may be derived from Richter's instrumental magnitude M by means of the following equation which is derived by Gutenberg and Richter (1942)[1]:

$$\log J^{\frac{1}{2}} = 6.0 + 0.9\,M \qquad \ldots\ldots\ldots (7)$$

In the two sequences represented in this study, magnitudes, hypocenters, and origin

[1] The constants in equation (7) represent the authors' latest revised values. The probable error is $\pm$ ½ magnitude.

TABLE 2.—TONGA-KERMADEC DEEP SEQUENCE (h = 70–680 km.)

Date	J.D.	ϕ	λ	M	$J^{\frac{1}{2}} \times 10^{12}$	$S \times 10^{12}$	h
1907, Apr. 1	2,417,667	18 S	177 W	7.25	3.30	3.30	400
1909, Feb. 22	18,361	18	179 W	7.5	5.60	8.90	550
1910, Apr. 21	18,784	20	177 W	7.0	2.00	10.90	330
1910, Aug. 21	18,906	17	179 W	7.25	3.30	14.20	600
1910, Dec. 15	19,022	21	178 W	7.0	2.00	16.20	600
1911, Apr. 29	19,157	27	179½ E	6.5	.70	16.90	600
1911, July 19	19,230	29	179 W	6.9	1.60	18.50	200
1911, Aug. 22	19,271	21	176 W	7.3	3.50	22.00	300
1912, May 15	19,539	30	178½ W	6.5	.70	22.70	250
1913, May 8	19,897	17	174½ W	7.0	2.00	24.70	200
1915, Feb. 26	20,556	20	180	7.25	3.30	28.00	600
1916, July 8	21,054	18	180	7.0	2.00	30.00	600
1918, May 22	21,737	17	177½ W	7.0	2.00	32.00	380
1918, Oct. 4	21,872	19	174 W	7.0	2.00	34.00	130
1919, Jan. 1	21,961	19½	176½ W	7.75	9.00	43.00	180
1919, Aug. 19	22,191	20½	178½ W	7.2	3.20	46.20	300
1922, Mar. 11	23,126	22	180	6.75	1.20	47.40	570
1924, Jan. 17	23,803	21	176 W	7.0	2.00	49.40	350
1924, May 5	23,912	21	178 W	7.3	3.50	52.96	560
1924, May 26	23,933	19	179 W	6.25	.42	53.32	550
1924, Dec. 27	24,148	21½	179 W	6.25	.42	53.74	540
1927, Apr. 2	24,974	20	177½ W	7.1	2.50	56.24	400
1928, June 17	2,425,416	21½ S	179½ W	6.25	.42	56.66	640
1928, Sept. 12	25,493	31	180	6.25	.42	57.08	500
1930, Apr. 30	26,098	20	176 W	6.75	1.20	58.28	180
1931, Apr. 4	26,437	20	179¾ W	6.75	1.20	59.48	680
1931, May 15	26,478	29	180	6.0	.20	59.68	500
1931, July 20	26,544	14	173 W	6.5	.70	60.38	80
1931, Oct. 18	26,634	26	180	6.75	1.20	61.58	500
1932, May 27	26,856	25½	179½ E	7.75	9.00	70.58	600
1932, May 27	26,856	25½	179½ E	6.5	.70	71.28	600
1932, May 27	26,856	25½	179½ E	6.25	.40	71.68	600
1932, May 27	26,856	25½	179½ E	5.75	.10	71.78	600
1932, June 17	26,877	20	176 W	6.0	.25	72.03	200
1932, July 21	26,911	27	178 W	6.5	.70	72.73	170
1932, Oct. 21	27,034	30	179 W	6.0	.25	72.98	70
1933, Jan. 24	27,098	21	180	6.25	.42	73.40	600
1933, May 21	27,246	35	180	6.0	.25	73.65	100
1933, June 12	27,267	22	176 W	6.5	.70	74.35	80
1933, Sept. 7	27,324	21½	179¾ W	7.1	2.50	76.85	600
1933, Nov. 8	27,386	30	177 W	5.5	.10	76.95	80
1934, Jan. 18	27,459	21	179 W	6.5	.70	77.65	580
1934, Feb. 10	27,480	20½	176½ W	6.5	.70	78.35	230
1934, Oct. 11	27,723	23½	180	7.3	3.50	81.85	540
1934, Sept. 23	27,735	30	177 W	6.0	.25	82.10	80
1934, Nov. 9	2,427,751	17½ S	174 W	6.25	.42	82.52	80
1934, Dec. 12	27,785	25	178 E	6.50	.70	83.22	600
1934, Dec. 16	27,789	23½	179½ W	6.9	1.60	84.82	530
1935, Jan. 2	27,806	17½	174½ W	7.1	2.50	87.32	300
1935, Apr. 20	27,914	31½	179½ W	5.75	.15	87.47	500
1935, July 16	28,001	20	178½ W	6.5	.70	88.17	580
1935, July 29	28,014	20¾	178 W	7.2	3.20	91.37	510

TABLE 1.—TONGA-KERMADEC SHALLOW SEQUENCE ($h < 70$ km.)

Date	J.D.	ϕ	λ	M	$J^{\frac{1}{2}} \times 10^{12}$	$S \times 10^{12}$
1910, June 29	2,418,852	32 S	176 W	7.0	2.0	2.0
1913, June 26	19,945	20	174	7.6	7.1	9.1
1917, May 1	21,350	29	177	8.0	16.0	25.1
1917, June 24	21,404	21	174	7.25	23.4	28.5
1917, June 26	21,406	15½	173	8.3	28.0	56.5
1917, Nov. 16	21,549	29	177½	7.5	5.6	62.1
1919, Apr. 17	22,066	29½	178	7.0	2.0	64.1
1919, Apr. 30	22,079	19	172½	8.3	28.0	92.1
1921, Feb. 27	22,748	18½	173	7.2	3.2	95.3
1924, Apr. 30	23,906	34	176	6.0	.2	95.5
1924, Aug. 10	24,008	30	178	6.75	1.2	96.7
1926, Mar. 16	24,591	16½	171	6.0	.2	96.9
1927, July 3	25,065	15	172½	6.25	.4	97.3
1929, Aug. 3	25,827	17	172½	6.5	.7	98.0
1930, Jan. 14	25,991	16	171	6.25	.4	98.4
1930, Feb. 14	26,022	21	175	6.5	.7	99.1
1930, Sept. 22	26,242	35½	179½	6.5	.7	99.8
1931, June 9	26,502	14	174	6.5	.7	100.5
1931, June 9	26,502	24½	176	6.25	.4	100.9
1931, Aug. 13	26,567	29	178	6.25	.4	101.3
1931, Nov. 18	26,664	20	174	6.0	.2	101.5
1932, Mar. 8	26,775	18½	179 E	6.25	.4	101.9
1932, Apr. 3	26,801	30¾	177½ W	6.25	.4	102.3
1932, May 22	2,426,850	20 S	174 W	6.25	.4	102.7
1933, Jan. 27	27,100	16	172	6.75	1.2	103.9
1933, Mar. 15	27,147	20	174	6.0	.2	104.1
1933, May 20	27,213	20	174½	6.0	.2	104.3
1933, June 18	27,242	15	172	6.0	.2	104.5
1933, July 24	27,278	16	173½	6.75	1.2	105.7
1934, Jan. 31	27,469	16	173½	6.25	.4	106.1
1934, Apr. 24	27,552	14	174	6.25	.4	106.5
1934, May 5	27,564	32	179	6.25	.4	106.9
1935, Feb. 4	27,838	20	174	6.25	.4	107.3
1935, Mar. 29	27,891	29	177½	6.25	.4	107.7
1935, Apr. 5	27,898	22	175	6.0	.2	107.9
1936, Mar. 20	28,248	14½	173½	6.25	.4	108.3
1936, Sept. 6	28,418	21½	174	6.0	.2	108.5
1939, Feb. 3	29,298	22½	175½	6.25	.4	108.9
1940, July 20	29,831	15½	173	6.0	.2	109.1
1940, Aug. 11	29,853	15½	172	6.0	.2	109.3
1940, Aug. 24	29,866	15½	173	6.0	.2	109.5
1941, Aug. 2	30,209	28½	178	7.1	2.5	112.0
1941, Sept. 16	30,254	28¾	177½	7.0	2.0	114.0
1941, Oct. 5	30,273	14½	173¾	6.5	.7	114.7
1942, Nov. 2	30,666	19	173	6.9	1.6	116.3
1942, Dec. 22	30,716	16¾	174	6.75	1.2	117.5
1943, June 3	2,430,879	16 S	173 W	6.5	.7	118.2
1943, Sept. 11	30,979	15	174	6.9	1.6	119.8
1943, Sept. 14	30,982	30	177	7.6	7.1	126.9
1943, Sept. 22	30,990	35½	178½	6.75	1.2	128.1
1943, Oct. 24	31,022	22	174	7.0	2.0	130.1
1943, Dec. 27	31,086	32	178½	6.25	.4	130.5
1943, Dec. 30	31,089	32½	177	6.25	.4	130.9
1946, Nov. 13	32,138	20	123½	7.5	5.6	136.5
1948, Sept. 9	32,804	21	174	8.0	16.0	152.5

TABLE 2.—*Continued*

Date	J.D.	ϕ	λ	M	$J^{\frac{1}{2}} \times 10^{12}$	$S \times 10^{12}$	h
1935, Aug. 22	2,428,038	16	174 W	6.25	.42	91.79	100
1935, Sept. 13	28,060	20	179 W	6.0	.25	92.04	600
1936, Feb. 11	28,211	18½	178 W	6.75	1.20	93.24	570
1936, Apr. 7	28,267	21	177 W	6.0	.25	93.49	100
1936, Nov. 16	28,490	21	178 W	6.5	.70	94.19	540
1936, Nov. 26	28,500	18½	178 W	6.5	.70	94.89	560
1937, Apr. 16	28,641	21½	177 W	7.75	9.00	103.89	400
1937, May 11	28,666	26½	178 E	6.50	.70	104.59	640
1937, June 20	28,706	26½	178 E	6.25	.40	104.99	650
1937, Sept. 1	28,809	32	180	7.0	2.00	106.99	120
1938, Mar. 7	28,965	19	178 W	6.0	.25	107.24	500
1938, Apr. 15	29,004	33	179 E	5.75	.15	107.39	580
1938, Apr. 25	29,014	19	176½ W	5.5	.10	107.49	400
1938, May 16	29,035	27	179 E	5.75	.15	107.64	600
1939, May 22	29,406	22½	179 W	6.0	.25	107.89	600
1942, Jan. 1	2,430,361	20½ S	180	6.25	.42	128.11	630
1942, June 16	30,527	21½	179 E	6.75	1.20	129.31	550
1942, July 7	30,548	21	178 W	6.75	1.20	130.51	430
1942, Aug. 29	30,601	24	179½ E	6.75	1.20	131.71	570
1943, Mar. 4	30,788	22	179½ W	6.0	.25	131.96	600
1943, Mar. 24	30,808	23	179 W	6.25	.42	132.38	430
1943, Apr. 29	30,844	24½	180	6.5	.70	133.08	530
1943, May 12	30,868	20	175 W	5.75	.15	133.23	270
1943, May 29	30,874	21	179½ W	6.5	.70	133.93	630
1943, June 26	30,902	18	178 W	6.25	.42	134.35	550
1943, July 11	30,917	32½	178½ W	7.0	2.00	136.35	180
1943, Sept. 28	30,996	30	178 W	7.1	2.50	138.85	90
1944, Apr. 23	31,204	22	177½ W	6.5	.70	139.55	370
1944, May 14	31,225	23	179½ E	6.0	.25	139.80	600
1944, May 25	31,236	21½	179½ W	7.2	3.20	143.00	640
1944, July 11	31,283	19½	175½ W	6.75	1.20	144.20	180
1944, Aug. 26	31,329	18	175½ W	6.25	.42	144.62	240
1944, Oct. 11	31,375	15	173½ W	6.75	1.20	145.82	80
1944, Nov. 14	31,406	24½	179½ E	6.0	.25	146.07	610
1944, Nov. 30	31,425	23	179 W	6.75	1.20	147.27	180
1944, Dec. 1	31,426	21	178½ W	6.4	.60	147.87	600
1945, Nov. 26	31,786	21	180	7.0	2.00	149.87	600
1946, Aug. 21	32,054	24	177 W	7.0	2.00	151.87	100
1946, Sept. 26	2,432,090	25 S	179 E	7.0	2.00	153.87	600
1946, Oct. 8	32,112	25	178 E	6.75	1.20	155.07	670
1946, Nov. 28	32,154	18½	174 W	6.75	1.20	156.27	290
1946, Dec. 17	32,172	21	177 W	6.5	.70	156.97	580
1947, July 13	32,381	19	175 W	6.25	.42	157.39	120
1948, Jan. 27	32,578	20	178 W	7.25	3.30	160.69	600?

mes were generously made available to me y Doctors Gutenberg and Richter from the anuscript of their book on *Seismicity of the arth* (1949). The shallow-focus magnitudes ere determined jointly by the two authors. he deep-focus magnitudes were determined Gutenberg (1945) using the method he veloped for this class of earthquake foci.

TONGA-KERMADEC SEQUENCES

The data for the Tonga-Kermadec sequences are given in Tables 1 and 2. The dates of origin have been converted into Julian days in order to simplify making of the graphs. In the tables t is the Julian day of origin, ϕ is the latitude of the epicenter, λ is the longitude of the

epicenter, h is the depth of focus in kilometers, and M is the magnitude. Figure 1 is a graph of S versus time for the shallow-earthquake sequence. Each circular dot represents the strain-relief increment of a single earthquake. The

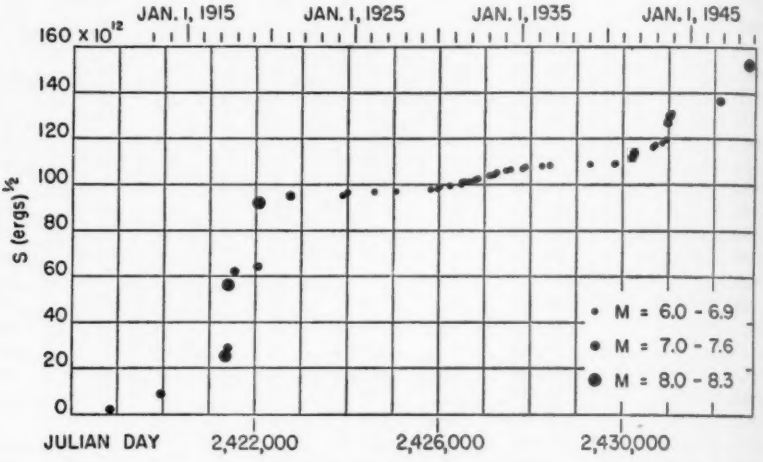


FIGURE 1.—STRAIN-REBOUND INCREMENTS OF TONGA-KERMADEC SHALLOW SEQUENCE (h < 70 km.) The plotted values are multiplied by the undetermined constant C of equation (5).

relation between the diameter of a dot and the magnitude of the earthquake with which it is associated is shown in the legend. This curve exhibits a rather large amount of irregularity—a characteristic found in a number of shallow sequences having large earthquakes. Presumably these sequences require greater time intervals than the present available maximum of 45 years of instrumental observations in order to show their characteristic trends. Figure 2 is a graph of S for the deep-focus sequence. This sequence includes all earthquakes of the region having focal depths greater than 70 km. which is taken to be the lower limit of the shallow earthquake sequence. The foci in this deep sequence are distributed uniformly to a depth of approximately 650 km. The curve of Figure 2 is made up of two phases. The graph of the first phase which ends at J.D. 2,426,634 (1931 October 18) was drawn from the calculated values of S in the equation

$$S_1 = [-257 + 79 \log t] \times 10^{13} \quad \ldots\ldots\ldots\ldots (8)$$

This equation represents a type of creep which has been observed in the laboratory for rocks (Griggs, 1939) and other solids (Lutts and Himmelfarb, 1940) subjected to constant compressional stress and which is designated elastic creep, since upon release of the stress the sample recovers completely—given enough time.

In engineering literature, creep of this kind is considered a manifestation of strain hardening. The second phase begins with the great earthquake of 1932 May 26 and continues to the present date. The curve for this phase was calculated from the equation

$$S_2 = -87.7 \times 10^{13} + 16.1 \times 10^9 t \quad \ldots\ldots\ldots\ldots (9)$$

This equation represents a movement with constant velocity. The smoothness and singular shapes of the curves representing the two phases provide convincing evidence that the sequence of earthquakes which they represent must have been generated on a single fault. On this basis, the origin of the two phases can be explained by reference to the schematic fault diagram shown in Figure 3. It is assumed that the fault surfaces were subject to stress in the directions shown by the arrows. The corresponding indentations and elevations A, B, C, D represent points or areas over which the fault surfaces were locked. When the stress at any one of these points exceeded the locking strength, faulting took place. In this way each point became in turn the focus of one of the

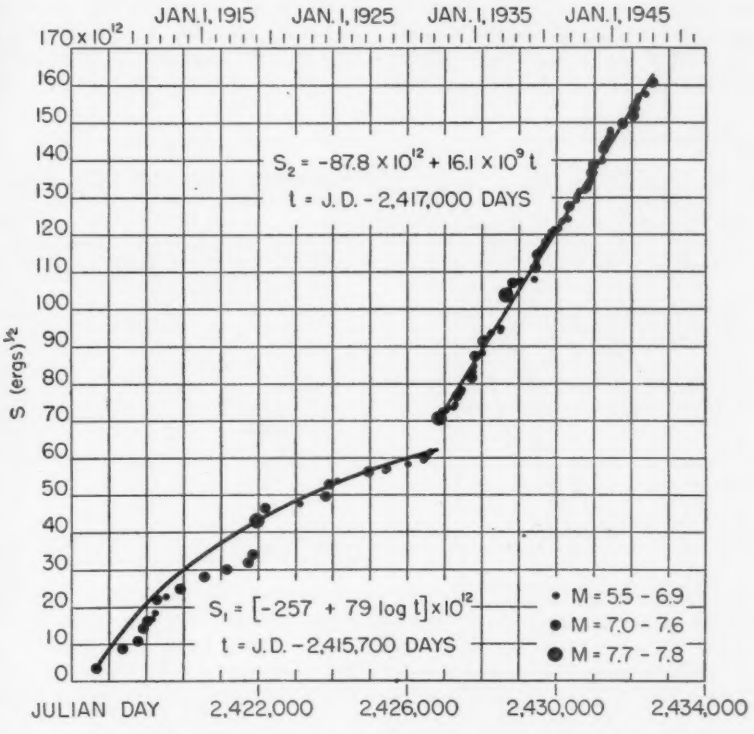


FIGURE 2.—STRAIN-REBOUND INCREMENTS OF TONGA-KERMADEC DEEP SEQUENCE (h = 70 — 480 km.) The plotted values are multiplied by the undetermined constant *C* of equation (5).

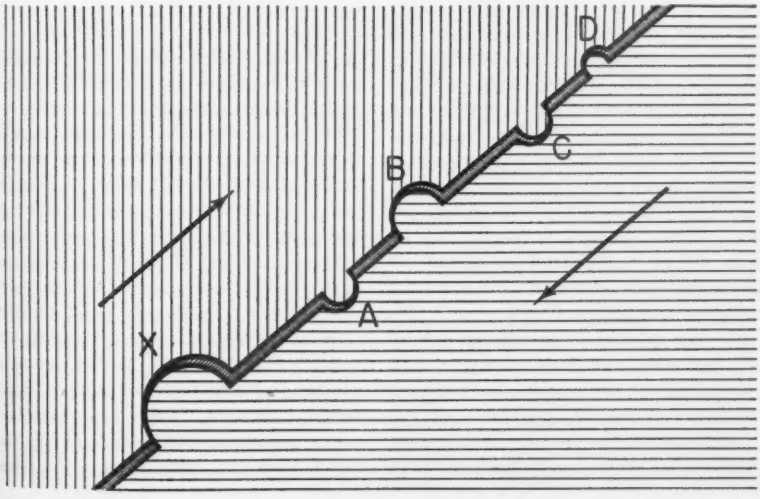


FIGURE 3.—TONGA-KERMADEC FAULT MECHANISM SUGGESTED BY STRAIN-REBOUND CURVE OF THE DEEP SEQUENCE

sequence earthquakes. In order to account for the shape of this first phase it must be assumed that one point X had a much higher locking strength than any of the others. At the time when the sequence began, faulting at the different minor points was frequent, and the block movements were rapid except in the vicinity of the major point X. The obstruction to the movements of the blocks presented by this point produced strain in the blocks which increased with time. As a result of this accumulating strain, the rate of movement of the blocks as well as the frequency of occurrence of the earthquakes decreased with time as shown by the graph of S_1. Finally on May 26, 1932, the stress at point X exceeded its locking strength, and this major obstruction gave way and thus generated the largest earthquake of the sequence. Thereafter movement of the blocks was resisted only by the minor surface irregularities, and consequently they proceeded rapidly at a uniform rate with no further accumulation of strain. The graph for S_1 which represents this movement is therefore a straight line. The great shock of May 26, 1932, occurred at a depth of 600 km. Moreover it produced a series of aftershocks, seven of which were large enough to be recorded in Pasadena.

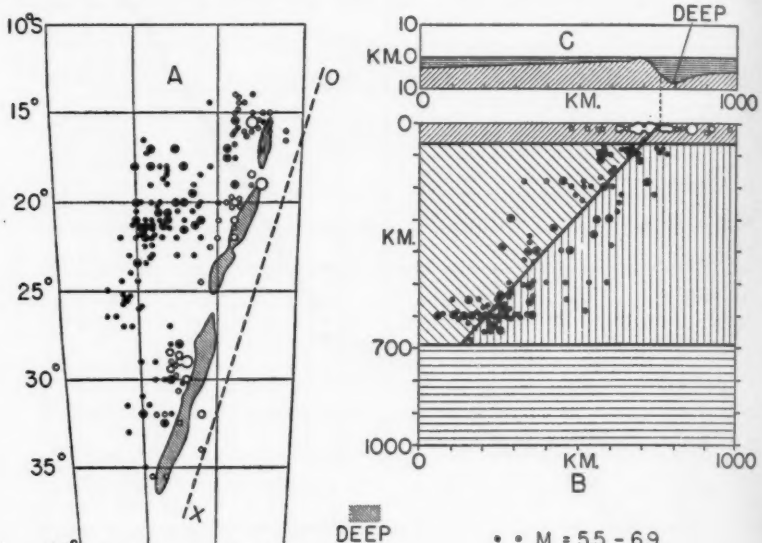


FIGURE 4.—TONGA-KERMADEC EARTHQUAKES AND OCEANIC DEEPS

The plane of the great fault intersects the earth's surface along the line of oceanic deeps. The slanting line in B represents the intersection of the fault with a vertical plane perpendicular to the line of oceanic deeps.

Since the curve for the shallow sequence (Fig. 1) bears no relationship to that of the deep sequence (Fig. 2) it may be concluded that there is no effective mechanical coupling between the two layers in which these sequences have their origins. Thus the boundary which separates them at a depth of approximately 70 km. must be a surface of profound discontinuity in the physical state or composition of the rock. The discontinuity in the seismic wave speed at this boundary appears to be quite small (Gutenberg, 1948). The absence of any term proportional to the time in equation (8) for S_1 indicates that although the layer, in

which this sequence originates, extends to a depth of nearly 700 km., the rock was able to maintain a stress without appreciable flow for 24 years.

Since the uncertainty in the location of the hypocenters in depth and geographical position can be indicated on the plane of the figure by a circle of approximately 100-km. radius it

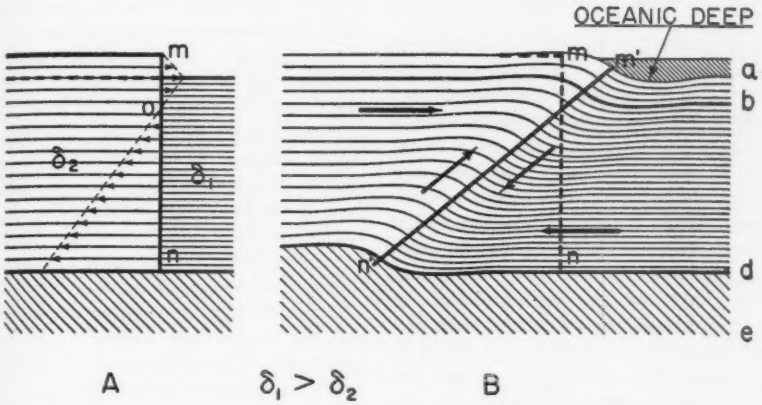


FIGURE 5.—SKETCH ILLUSTRATING PROPOSED ORIGIN OF THE GREAT TONGA-KERMADEC FAULT

A map of epicenters of the Tonga-Kermadec sequences is shown in Figure 4A. The neighboring oceanic deeps are also indicated. The epicenters of shallow-focus earthquakes are shown as open circles. while those of deep-focus shocks are represented by solid circles. Figure 4B represents a vertical section of the region taken perpendicular to the line *OX* which was drawn parallel to the trend of the oceanic deeps. The hypocenters corresponding to the epicenters of Figure 4A are shown projected horizontally on the section. In this drawing the vertical and horizontal scales are equal. The oceanic deeps are not shown since, to scale, their depth is about equal to the width of a line. Figure 4C represents an average profile of the upper 10 kilometers of the region, with the vertical scale exaggerated ten fold in order to show the oceanic deeps. The heavy horizontal line at the 70-km. depth represents the discontinuity between the shallow and deep layers. The heavy horizontal line at the 690 km. depth indicates the discontinuity between the seismically active deep layer and the layer below in which presumably secular strains of the kind that produce earthquakes do not or cannot exist. The heavy oblique line represents the average distribution of the projected foci. may be assumed that if the observational errors were small enough all the points would lie on or close to the line. Thus we may assume that the hypocenters determine an oblique fault having a plane surface indicated in the figure by the line, and that this is the fault determined by the strain-rebound curves. If the spread in the points is real they determine a fault zone which is still fairly narrow in comparison with its length. The fault plane cuts the earth's surface along the steep western slopes of the oceanic deeps (Fig. 4C). The total length of the fault as shown on the Map Figure 4A is approximately 2500 km. (1500 mi.). The transverse dimension measured along the oblique intersection is approximately 900 km. (540 mi.). This great fault is thus larger than any previously known active fault. A simple hypothesis as to its origin can be described with the help of Figure 5. Assume that originally a continental mass of density δ_2 was in contact along the surface *mn* with an oceanic mass of density δ_1 (Fig. 5A). As a result of secular flow in the rock masses a hydrostatic pressure $gh_1\delta_1$ developed at the depth h_1 within the oceanic mass, and a corresponding pressure $gh_2\delta_2$ developed at a depth h_2 within the continental mass. The constant g is the acceleration of

gravity. Thus at any given point on the contact surface *mn* the two pressures produced a differential stress, acting perpendicular to the boundary, given by their difference Δ, where

$$\Delta = (h_1\delta_1 - h_2\delta_2)g$$

A possible distribution with respect to depth of the differential stress Δ is represented on an arbitrary scale in the figure. The direction and distance of the arrows from the line *mn* indicate the direction and intensity of the stress. At the bottom of the deeper layer the differential stress was greatest and was directed toward the continental mass. It decreased linearly toward shallower depths as indicated by the light dashed line drawn through the arrow heads. At some level near the earth's surface the greater height h_2 of the continental mass relative to that of the oceanic mass h_1 offset its lower density, and the differential pressure was zero as at *O* in the figure. Above this level the hydrostatic pressure in the continental mass was greater than that in the denser oceanic mass, and the differential stress was therefore directed toward the oceanic mass. It passed through a secondary maximum at the level of the oceanic mass surface and fell to zero at the continental surface.

Acting over a sufficiently long interval of time this differential stress pattern produced a distortion of the two masses which resulted in a configuration such as shown in Figure 5B. Near the surface the continental mass flowed over the oceanic mass, while in the depths the oceanic mass pushed under the continental mass. Thus the originally vertical contact surface *mn* became the inclined surface *m'n'*. Below the level at which the differential pressure was zero the parallel component was directed downward on the oceanic side of the contact, and above this level it was directed upward on the continental side. Thus the parallel stress components transformed the contact into a fault in which the oceanic block moves downward and the continental block moves upward along the oblique fault plane. The surface distortions resulting from the faulting stresses are indicated in the figure. The downwarping of the oceanic block thus produced the depressions which form the oceanic deeps.

South American Earthquake Sequences

The observed data for the South American sequences are given in Tables 3, 4, and 5. A graph of *S* for the shallow-earthquake sequence is shown in Figure 6. For the period of time over which observations are available this graph is a straight line. On the basis of a single fault structure the straight line indicates that the fault block moves at a uniform rate.

Figure 7 is a graph of *S* for the intermediate-depth sequence (*h=70–300 km.*) drawn on semilog co-ordinates. In this graph *S* takes the form of two intersecting straight lines. If plotted on arithmetic co-ordinates these lines would be exponential curves concave upward. They represent flows which increase exponentially with time. If these movements are produced in response to constant stresses acting on the fault rocks, they correspond to a type of creep which is characteristic of substances maintained in the annealing range of temperature above the strain-hardening limit. Since the rate of flow is curvilinear with respect to time and presumably with respect to stress it is defined as plastic flow. (A viscous flow is linear in relation to stress. The flow contribution in strain is not recovered upon release of stress.) On May 20, 1918, JD 2,421,734, the first phase ended. After an interval of 2¼ years the second phase began on August 13, 1920, with a reduced rate. Discontinuities of this type have been observed in a number of other sequences studied by the writer. Their cause remains obscure. They must represent sudden changes in stress, friction, or physical state of the fault masses. In any case it is difficult to understand how changes can occur throughout such large structures in such short intervals of time.

A graph of *S* plotted against time for the deep-focus sequence (*h=550–660 km.*) is shown in Figure 8. This graph takes the form of intersecting straight lines in linear co-ordinates, indicating constant velocity movements of the fault blocks. From the date at which observations began April 28, 1911, until January 17, 1922, the block velocity was large, and the earthquakes which determined it were large. After that interval the earthquake frequency increased appreciably, while the magnitudes

TABLE 3.—SOUTH AMERICAN SHALLOW SEQUENCE ($h < 70$ km.)

Date	J.D.	ϕ	λ	M	$J^{\frac{1}{2}} \times 10^{13}$	$S \times 10^{13}$
1906, Jan. 31	2,417,242	1 N	81½ W	8.6	55.0	55.0
1906, Aug. 17	17,440	33 S	72	8.4	35.0	90.0
1909, June 8	18,466	26½ S	70½	7.6	7.1	97.1
1911, Sept. 15	19,295	20 S	72	7.3	3.5	100.6
1913, July 28	19,977	17 S	74	7.0	2.0	102.6
1913, Aug. 6	19,986	17 S	74	7.75	9.5	112.1
1914, Jan. 30	20,163	35 S	73	7.6	7:1	119.2
1917, Feb. 15	21,275	30 S	73	7.0	2.0	121.2
1917, July 27	21,437	31 S	70	7.0	2.0	123.2
1917, Aug. 31	21,470	4 N	74	7.3	3.5	126.7
1918, Dec. 4	21,932	26 S	71	7.75	9.5	136.2
1920, Jan. 30	22,354	3 N	77½	6.0	.2	136.4
1920, Aug. 3	22,540	27½ S	70	6.75	1.2	137.6
1920, Sept. 24	22,592	6 N	83	6.5	.7	138.3
1922, Jan. 6	23,061	16½ S	73	7.2	3.2	141.5
1922, Oct. 11	23,339	16 S	72½	7.4	4.5	146.0
1922, Nov. 7	23,366	28 S	72	7.0	2.0	148.0
1922, Nov. 11	23,368	28½ S	70	8.3	28.0	176.0
1923, May 4	23,544	28½ S	71½	7.0	2.0	178.0
1924, Mar. 11	23,856	4 S	82	6.75	1.2	179.2
1924, June 22	23,959	5½ N	78½	6.5	.7	179.9
1924, Oct. 18	24,077	2½ N	80	6.75	1.2	181.1
1925, May 15	24,286	26 S	71½	7.1	2.5	183.6
1926, Aug. 12	2,424,740	23 S	70 W	6.75	1.2	184.8
1927, Mar. 13	24,953	6 S	81½	6.0	.2	185.0
1927, Aug. 20	25,113	5 N	82½	7.0	2.0	187.0
1927, Nov. 14	25,199	30½ S	71½	6.75	1.2	188.2
1928, Apr. 9	25,346	13 S	69½	6.9	1.6	189.8
1928, Apr. 27	25,364	13 S	69½	6.75	1.2	191.0
1928, May 14	25,381	5 S	78	7.3	3.5	194.5
1928, July 18	25,446	5½ S	79	7.0	2.0	196.5
1928, July 28	25,456	31 S	71	6.5	.7	197.2
1928, Nov. 20	25,561	22½ S	70½	7.1	2.5	199.7
1928, Dec. 1	25,572	35 S	72	8.0	16.0	215.7
1929, May 30	25,762	35 S	68	6.75	1.2	216.9
1929, Aug. 15	25,839	5 N	83½	6.5	.7	219.6
1930, Dec. 24	26,335	25 S	66	6.0	.2	217.8
1931, Mar. 18	26,419	32½ S	72	7.1	2.5	220.3
1931, Apr. 3	26,435	9½ S	79	6.25	.4	220.7
1931, May 20	26,482	27½ S	71½	6.25	.4	221.1
1931, June 15	26,508	14½ S	75½	6.0	.2	221.3
1931, June 29	26,522	29½ S	71	6.0	.2	221.5
1931, Sept. 12	26,597	5 N	77½	6.25	.4	221.9
1932, Sept. 5	26,956	6 S	81	6.0	.2	222.1
1933, Feb. 23	27,127	20 S	71	7.6	7.1	229.2
1933, May 6	27,199	5½ N	83	6.5	.7	229.9
1933, May 6	2,427,199	5½ N	82½ W	6.0	.2	230.1
1933, Oct. 2	27,348	2 S	81	6.9	1.6	231.7
1933, Oct. 3	27,349	1¾ S	80¾	6.25	.4	232.1
1933, Oct. 3	27,349	1¾ S	80¾	6.0	.2	232.3
1934, Apr. 3	27,531	4 N	78	6.0	.2	232.5
1934, Aug. 6	27,656	3½ N	77½	6.0	.2	232.7

TABLE 3.—*Continued*

Date	J.D.	ϕ	λ	M	$J^{\frac{1}{2}} \times 10^{11}$	$S \times 10^{9}$
1935, June 28	2,427,982	34 S	73	6.0	.2	232.9
1935, Aug. 5	28,021	35 S	72	6.0	.2	233.1
1935, Dec. 24	28,161	3 N	79	6.75	1.2	234.3
1936, May 22	28,311	32 S	66	6.0	.2	234.5
1936, July 13	28,363	24½ S	70	7.3	3.5	238.0
1936, July 26	28,376	24 S	70	6.75	1.2	239.2
1937, March 14	28,607	24½ S	69½	6.5	.7	239.9
1937, June 21	28,706	8½ S	80	6.75	1.2	241.1
1937, July 8	28,723	3 N	84	6.0	.2	241.3
1937, Dec. 12	28,880	25 S	70	6.0	.2	241.5
1937, Dec. 24	28,893	10½ S	76½	6.25	.4	241.9
1938, Apr. 17	29,016	19 S	69½	6.5	.7	242.6
1939, Sept. 20	29,527	11½ S	75½	6.0	.2	242.8
1940, March 31	29,720	19 S	70½	6.0	.2	243.0
1940, Apr. 8	29,728	33½ S	71½	6.0	.2	243.2
1940, May 5	29,755	7 S	80	6.0	.2	243.4
1940, May 24	29,774	10½ S	77	8.0	16.0	259.4
1940, Oct. 6	2,429,909	22 S	71 W	6.75	1.2	260.6
1941, July 3	30,179	31½ S	69½	6.25	.4	261.0
1941, July 11	30,187	5 N	82½	6.25	.4	261.4
1942, May 14	30,525	¾ S	81½	7.9	13.0	274.4
1942, Aug. 24	30,596	15 S	76	8.1	20.0	294.4
1942, Oct. 8	30,641	6 N	82½	6.0	.2	294.6
1943, Mar. 5	30,789	5½ N	82½	6.75	1.2	295.8
1943, Apr. 6	30,821	30¾ S	72	7.9	13.0	308.8
1943, May 22	30,867	30¾ S	72	6.75	1.2	310.0
1943, July 5	30,911	16 S	74	6.75	1.2	311.2
1944, Jan. 15	31,095	31½ S	68¾	7.4	4.5	315.7
1944, Oct. 23	31,387	½ N	80½	6.9	1.6	317.3
1946, Aug. 2	32,035	26½ S	70½ W	7.5	5.6	322.9
1946, Nov. 10	32,135	8½ S	77½	7.25	3.4	326.3
1947, Nov. 1	32,491	10½ S	75	7.3	3.5	329.8

decreased sufficiently to reduce the block velocity to 0.22 of its initial value. There is some indication that in January 1946 the initial rate of the blocks was resumed, but more time will be required to settle this question. It is noteworthy that the discontinuity in this deep sequence occurred very nearly at the same time that the intermediate-sequence discontinuity occurred and that in each the rate decreased. This would indicate that a certain amount of mechanical coupling exists between the two layers in which these sequences have their origins. On the other hand there is no evidence of coupling between the shallow and intermediate layers. The boundary between them must represent a profound mechanical discontinuity similar to the corresponding boundary in the Tonga-Kermadec region. Possibly, since the shallow sequences generally show greater strain-rebound movements than the deeper sequences, the shallow movements may include movements coupled with the deeper layers along with horizontal or other movements which are independent of them. On this basis, however, we would expect to observe some effect of the lower-layer velocity discontinuities on the surface-layer movements, unless the movements in the two layers are complementary. These effects appear to be lacking in both the Tonga-Kermadec region and in South America. There is some evidence that faulting in the shallow layers of both these regions is principally horizontal. Nevertheless these layers are sufficiently thin in relation to the thick-

TABLE 4.—SOUTH AMERICAN INTERMEDIATE SEQUENCE (h = 70–300 km.)

Date	J.D.	ϕ	λ	M	$J^{\frac{1}{2}} \times 10^{13}$	$S \times 10^{13}$	h
1906, Sept. 28	2,417,482	2 S	79 W	7.5	5.6	5.6	150
1909, May 17	18,444	20 S	64 W	7.1	2.5	8.1	250
1910, Oct. 4	18,949	22 S	69 W	7.25	3.4	11.5	120
1914, Feb. 26	20,190	18 S	67 W	7.2	3.2	14.7	130
1915, June 6	20,655	18½ S	68½ W	7.6	7.1	21.8	160
1916, Aug. 25	21,101	21 S	68 W	7.5	5.6	27.4	180
1918, May 20	21,734	28½ S	71½ W	7.5	5.6	33.0	80
1920, Aug. 13	22,612	20 S	68 W	6.5	.7	33.7	150
1921, Oct. 20	22,983	18½ S	68 W	7.0	2.0	35.7	120
1922, Mar. 28	23,142	21 S	68 W	7.2	3.2	38.9	90
1923, Sept. 2	23,665	16 S	68½ W	7.0	2.0	40.9	150
1924, July 22	23,989	2 S	80 W	6.5	.7	41.6	250
1925, Jan. 5	24,156	14 S	73½ W	6.5	.7	42.3	200
1925, June 7	24,309	3 N	78 W	6.75	1.2	43.5	170
1925, June 23	24,325	0	77 W	6.75	1.2	44.7	180
1926, Mar. 7	24,582	5 S	76½ W	6.5	.7	45.4	150
1926, Apr. 28	24,634	24 S	69 W	7.0	2.0	47.4	180
1927, Apr. 14	24,985	32 S	69½ W	7.1	2.5	49.9	110
1927, May 22	25,023	21 S	67 W	6.25	.4	50.3	140
1927, Aug. 1	25,094	24 S	66½ W	6.5	.7	51.0	200
1927, Oct. 3	25,157	21 S	68 W	6.5	.7	51.7	100
1927, Nov. 26	25,211	24½ S	67 W	6.75	1.2	52.9	180
1928, May 26	25,393	23½ S	69 W	6.25	.4	53.3	130
1928, Sept. 21	2,425,501	15 S	70½ W	6.75	1.2	54.5	250
1929, May 25	25,757	8½ S	75½ W	6.75	1.2	55.7	150
1929, Oct. 19	25,904	23 S	69 W	7.5	5.6	61.3	100
1929, Oct. 19	25,904	23 S	69 W	6.0	.2	61.5	100
1930, Sept. 23	26,243	26 S	66 W	6.5	.7	62.2	150
1930, Nov. 24	26,305	2 S	77 W	6.25	.4	62.6	100
1931, Apr. 3	26,435	27 S	65 W	6.25	.4	63.0	180
1931, May 28	26,490	20½ S	70½ W	6.5	.7	63.7	120
1931, July 11	26,534	8½ S	74½ W	6.25	.4	64.1	120
1931, July 18	26,541	22½ S	69 W	6.75	1.2	65.3	150
1932, Jan. 20	26,727	12 S	77½ W	6.75	1.2	66.5	100
1932, Apr. 26	26,824	25 S	69½ W	6.5	.7	67.2	70
1932, June 18	26,877	20 S	71 W	6.25	.4	67.6	70
1932, July 29	26,918	19 S	70 W	6.0	.2	67.8	110
1932, Nov. 1	27,013	24 S	70 W	6.0	.2	68.0	100
1932, Nov. 29	27,041	32 S	71 W	6.75	1.2	69.2	110
1932, Dec. 9	27,051	15 S	75 W	6.5	.7	69.9	75
1933, July 23	27,277	15½ S	75½ W	6.0	.2	70.1	80
1933, July 31	27,285	15½ S	75½ W	6.0	.2	70.3	80
1933, Aug. 6	27,291	11 S	75½ W	6.5	.7	71.0	100
1933, Aug. 9	27,294	15½ S	68½ W	6.25	.4	71.4	170
1933, Oct. 1	27,347	7 S	75½ W	6.25	.4	71.8	120
1933, Oct. 12	27,358	23 S	69½ W	6.25	.4	72.2	100
1933, Oct. 25	2,427,371	23.0 S	66.7 W	7.0	2.0	74.2	220
1933, Nov. 14	27,391	32 S	69½ W	6.5	.7	74.9	110
1933, Dec. 21	27,398	31 S	69 W	6.25	.4	75.3	120
1934, June 11	27,600	33½ S	64½ W	6.0	.2	75.5	100
1934, June 11	27,600	33½ S	64½ W	6.0	.2	75.7	100
1934, June 24	27,613	22.0 S	68.6 W	6.9	1.6	77.3	100

TABLE 4.—*Continued*

Date	J.D.	ϕ	λ	M	$J^{\frac{1}{2}} \times 10^{12}$	$S \times 10^{12}$	h
1934, Oct. 29	2,427,740	5 S	78 W	6.25	.4	77.7	110
1934, Dec. 4	27,775	19½ S	69½ W	6.9	1.6	79.3	130
1934, Dec. 16	27,787	24 S	68 W	6.0	.2	79.5	150
1934, Dec. 23	27,794	21 S	68 W	6.5	.7	80.2	100
1935, Feb. 13	27,847	25½ S	69 W	6.5	.7	80.9	100
1935, Feb. 28	27,862	23 S	67 W	6.25	.4	81.3	200
1935, Mar. 8	27,870	4 S	80 W	6.0	.2	81.5	100
1935, Mar. 26	27,888	15½ S	73 W	6.0	.2	81.7	120
1935, Sept. 18	28,064	5½ N	76 W	6.25	.4	82.1	80
1935, Sept. 19	28,065	15½ S	70 W	6.5	.7	82.8	250
1935, Nov. 2	28,109	2 S	79 W	6.0	.2	83.0	130
1936, Apr. 30	28,289	31 S	65 W	6.0	.2	83.2	200
1936, May 6	28,295	8 S	75 W	6.0	.2	83.4	160
1936, June 22	28,342	22 S	68 W	6.0	.2	83.6	100
1936, July 4	28,354	18 S	70 W	6.0	.2	83.8	140
1936, Nov. 7	28,480	23 S	67 W	6.0	.2	84.0	200
1936, Nov. 29	28,502	22½ S	67 W	6.0	.2	84.2	230
1936, Dec. 5	28,508	20 S	70½ W	6.0	.2	84.4	100
1937, Mar. 19	2,428,612	29 S	70 W	6.0	.2	84.6	70
1937, Mar. 29	28,622	15½ S	71 W	6.75	1.2	85.8	120
1937, May 21	28,675	2½ N	77½ W	6.5	.7	86.5	90
1937, July 9	28,724	16 S	72 W	6.0	.2	86.7	180
1937, July 19	28,734	1½ S	76½ W	7.1	2.2	88.9	190
1937, Sept. 24	28,801	22½ S	70 W	6.0	.2	89.1	130
1937, Oct. 12	28,819	25 S	68½ W	6.5	.7	89.8	110
1937, Oct. 27	28,834	34½ S	71 W	6.0	.2	90.0	110
1938, Jan. 16	28,915	6 S	75 W	6.0	.2	90.2	100
1938, Feb. 5	28,935	4½ N	76¼ W	7.0	2.0	92.2	160
1938, Apr. 24	29,013	23½ S	66 W	6.0	.2	92.4	180
1938, June 15	29,065	31 S	70½ W	6.0	.2	92.6	70
1938, June 23	29,073	30½ S	70 W	6.5	.7	93.3	70
1938, Aug. 4	29,115	24 S	68 W	6.75	1.2	94.5	220
1939, Jan. 18	29,292	29½ S	71 W	6.25	.4	94.9	70
1939, Apr. 18	29,372	27 S	70½ W	7.4	4.5	99.4	100
1939, Apr. 25	29,379	12½ S	75½ W	6.25	.4	99.8	150
1939, May 19	29,403	18 S	69 W	6.25	.4	100.2	100
1939, July 4	29,449	21 S	66 W	6.75	1.2	101.4	290
1939, Oct. 5	29,542	22 S	67 W	6.0	.2	101.6	240
1939, Oct. 7	29,544	18½ S	70 W	6.0	.2	101.8	110
1940, Feb. 12	29,672	26½ S	71 W	6.5	.7	102.5	70
1940, Aug. 7	29,849	22 S	68½ W	6.25	.4	102.9	110
1940, Aug. 26	29,868	11½ S	75 W	6.0	.2	103.1	110
1940, Sept. 18	2,429,891	23 S	68 W	6.5	.7	103.8	110
1940, Sept. 29	29,902	35 S	70 W	6.25	.4	104.2	110
1940, Oct. 1	29,904	30 S	72½ W	6.5	.7	104.9	80
1940, Oct. 3	29,906	21 S	70 W	6.25	.4	105.3	110
1940, Oct. 4	29,907	22 S	71 W	7.3	3.5	108.8	75
1940, Oct. 23	29,926	2`S	76 W	6.0	.2	109.0	140
1940, Oct. 24	29,927	35 S	72½ W	6.75	1.2	110.2	80
1940, Dec. 22	29,986	15½ S	68½ W	7.1	2.5	112.7	230
1941, Jan. 24	30,019	3½ S	76¾ W	6.5	.7	113.4	120
1941, Apr. 3	30,088	22½ S	66 W	6.5	.7	114.1	260

TABLE 4.—*Continued*

Date	J.D.	ϕ	λ	M	$J^{\frac{1}{2}} \times 10^{12}$	$S \times 10^{12}$	h
1941, Apr. 3	2,430,088	22½ S	66 W	7.2	3.2	117.3	260
1941, July 10	30,186	18½ S	70 W	6.0	.2	117.5	120
1941, Aug. 14	30,221	23 S	66½ W	6.0	.2	117.7	180
1941, Sept. 18	30,256	13¾ S	72½ W	7.0	2.0	119.7	100
1941, Oct. 15	30,283	15½ S	74 W	6.0	.2	119.9	110
1941, Nov. 10	30,309	22 S	67 W	6.25	.4	120.3	200
1942, June 29	30,540	32 S	71 W	6.9	1.6	121.9	100
1942, July 8	30,549	24 S	70 W	7.0	2.0	123.9	140
1942, Nov. 6	30,670	6 S	77 W	6.75	1.2	125.1	130
1943, Jan. 30	30,755	2 S	80½ W	6.9	1.6	126.7	100
1943, Feb. 16	30,772	15 S	72 W	7.0	2.0	128.7	190
1943, Mar. 14	30,798	20 S	69½ W	7.2	3.2	131.9	150
1943, Apr. 5	2,430,820	6½ S	76 W	6.5	.7	132.6	140
1943, Nov. 29	31,058	29½ S	68½ W	6.75	1.2	133.8	100
1943, Dec. 1	31,060	21 S	69 W	7.25	3.4	137.2	100
1943, Dec. 22	31,081	2½ S	77 W	6.25	.4	137.6	130
1944, Feb. 29	31,150	14½ S	70½ W	7.0	2.0	139.6	200
1944, May 9	31,220	2½ N	75½ W	6.0	.2	139.8	100
1944, July 23	31,295	24 S	66½ W	6.0	.2	140.0	250
1944, Dec. 22	31,447	25 S	70 W	6.5	.7	140.7	120
1945, July 9	31,646	2½ N	76½ W	6.5	.7	141.4	100
1945, Aug. 21	31,689	10½ S	75 W	6.75	1.2	142.6	120
1945, Sept. 13	31,712	33½ S	70½ W	7.1	2.5	145.1	100
1946, July 26	32,028	19¾ S	70½ W	6.75	1.2	146.3	70
1946, Sept. 30	32,094	13 S	76 W	7.0	2.0	148.3	70

TABLE 5.—SOUTH AMERICA DEEP SEQUENCE (h = *550–660 km.*)

Date	J.D.	ϕ	λ	M	$J^{\frac{1}{2}} \times 10^{12}$	$S \times 10^{12}$	h
1911, Apr. 28	2,419,156	0 S	71 W	7.1	2.50	2.50	600
1912, Dec. 7	19,746	29	62½	7.5	5.60	8.10	620
1915, Apr. 23	20,613	8	68	7.25	3.30	11.40	650
1916 June 21	21,038	28½	63	7.5	5.60	17.00	600
1921, Dec. 18	23,044	2½	71	7.6	7.10	24.10	650
1922, Jan. 17	23,073	2½	71	7.6	7.10	31.20	650
1922, July 10	23,247	19	62	6.75	1.20	32.40	630
1922, Sept. 4	23,303	10½	69½	6.9	1.60	34.00	660
1926, Feb. 9	24,557	29	62	6.5	.70	34.70	660
1927, Apr. 6	24,979	10	70	6.0	.25	34.95	600
1928, Jan. 5	25,253	19½	64	6.75	1.20	36.15	640
1928, Aug. 15	25,466	28	62½	6.50	.70	36.85	620
1930, Aug. 4	26,194	9½	70½	6.50	.70	37.55	650
1933, Aug. 29	27,310	10.9	69.5	6.50	.70	38.25	650
1934, Jan. 9	27,448	28½	63	6.0	.25	38.50	630
1935, Dec. 14	28,152	9½	70½	6.9	1.60	40.10	650
1935, Dec. 16	28,155	9½	70½	6.25	.42	40.52	600
1935, Dec. 28	28,167	9½	70½	5.75	.15	40.67	650
1936, Jan. 14	28,183	29	62½	6.9	1.60	42.27	620
1939, Jan. 24	29,289	26½	63	6.0	.25	42.52	580
1939, Dec. 4	29,623	6½	70	5.5	.10	42.62	600
1940, May 1	29,751	25½	62½	6.25	.42	43.04	580
1940, Sept. 23	2,429,896	23 S	64 W	6.5	.70	43.74	550
1940, Sept. 24	29,897	9½	70½	6.0	.25	43.99	600
1942, Nov. 30	30,694	27	63½	6.5	.70	44.69	590
1944, June 8	31,250	10	71	6.25	.42	45.11	600
1946, Aug. 28	32,061	26	63	7.20	3.20	48.31	580
1947, Jan. 29	32,215	26	63	7.25	3.30	51.61	580
1947, Aug. 6	32,404	9	72	6.75	1.20	52.81	600

ness of the deeper layers that they can take on the vertical warping produced by the vertically oblique faulting of these larger deep structures even though their own faulting move-

ditional earthquakes occurred for 5½ yea
During this interval the strain continued
accumulate at the initial constant rate so th
when the fault did give way it generated

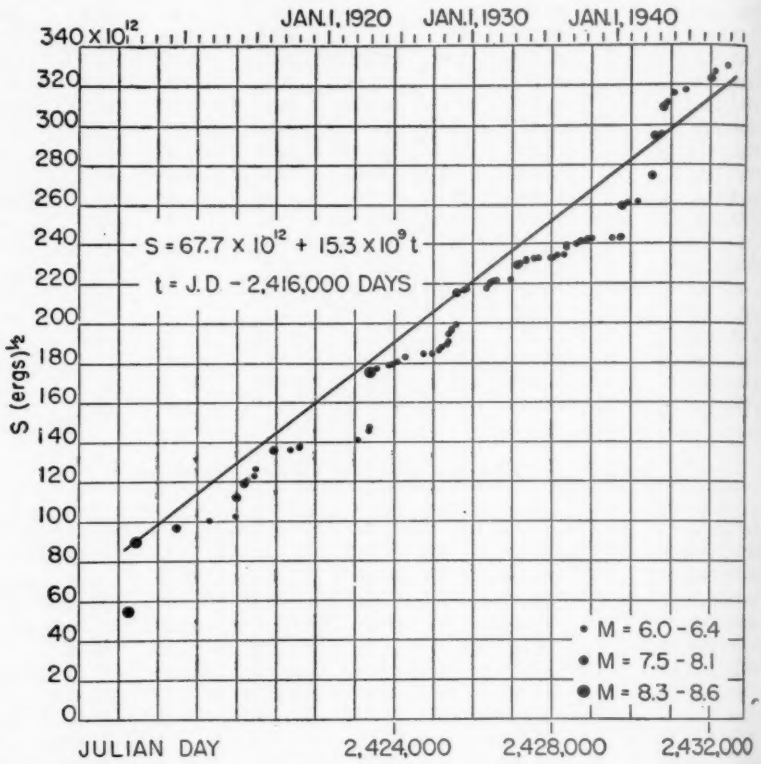


FIGURE 6.—STRAIN-REBOUND INCREMENTS OF THE SOUTH AMERICAN SHALLOW SEQUENCE (h < 70 km.)
The plotted values are multiplied by the undetermined constant C of equation (5).

ment may not conform with those of the deeper faults.

In Figure 9 the deep-focus sequence consists of two groups of epicenters centered roughly at 5° and 25° latitude south, respectively. Each group has the same number of shocks and in addition the same number in each indicated magnitude range. Thus although they represent areas of the fault block which are some 2000 km. apart their movements are very nearly identical. In the initial phase of this sequence (Fig. 8) the fault locked strongly following the fourth earthquake, and no ad-

great earthquakes which brought the tota
elastic-rebound movement to the value de
termined by the initial line. Thus for a perio
of 5½ years the rock of this fault maintained
linear elastic strain without flow at a depth o
650 kilometers. Clearly any remaining doubt
as to the solidity of rocks at such depths must
be abandoned.

A map of the region of the South American
sequences is shown in Figure 9. Epicenters o
shallow-focus earthquakes are shown as open
circles. Those of intermediate-depth foci are
shown as solid circles, and the deep-focus ep

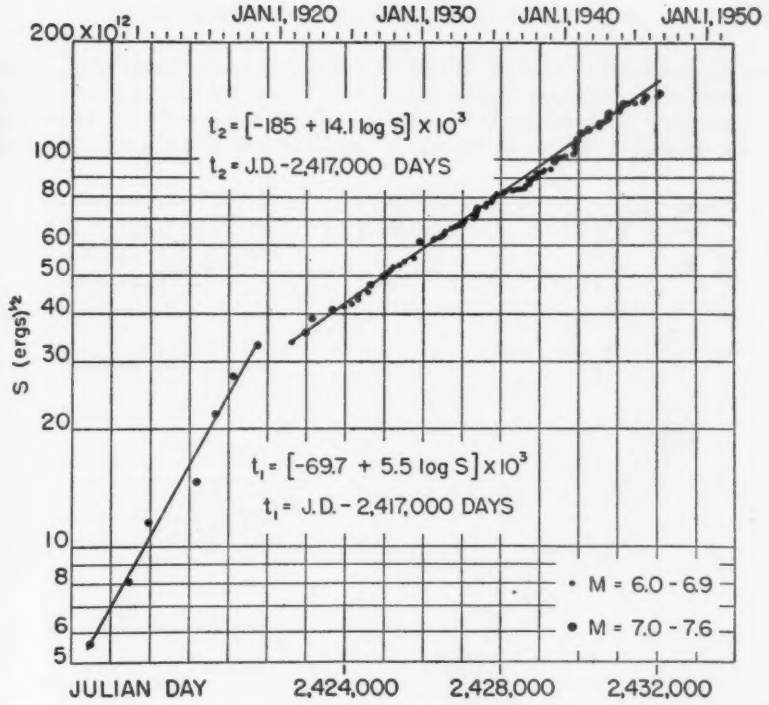


FIGURE 7.—STRAIN-REBOUND INCREMENTS OF THE SOUTH AMERICAN INTERMEDIATE SEQUENCE (h = 70 — 300 km.)
The plotted values are multiplied by the undetermined constant *C* of equation (5).

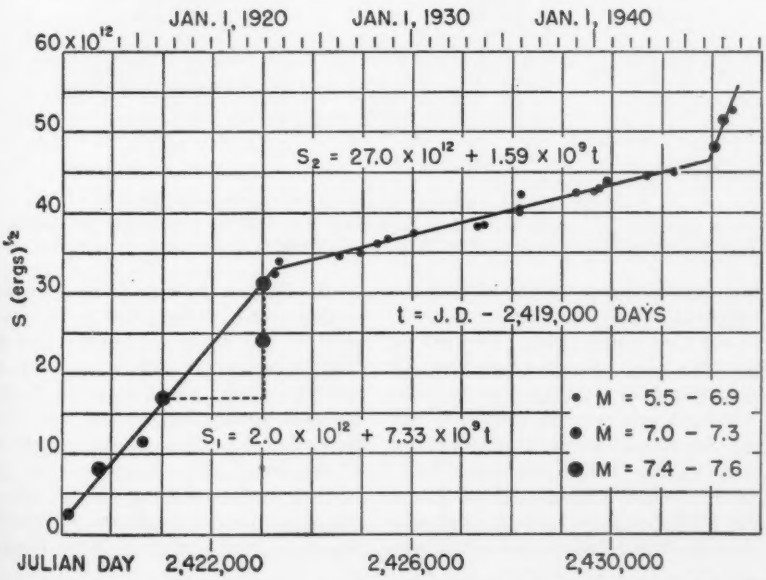


FIGURE 8.—STRAIN-REBOUND INCREMENTS OF THE SOUTH AMERICAN DEEP SEQUENCE (h = 550 — 660 km.)
The plotted values are multiplied by the undetermined constant C of equation (5).

centers are represented by triangles. The magnitude ranges of the earthquakes corresponding to the epicenters are indicated. The oceanic deeps are sketched in roughly. In this region which were drawn parallel to the neighboring deeps. Above each section is drawn an average profile of the upper 10 km. of the projected region of each section outlined by the dashed

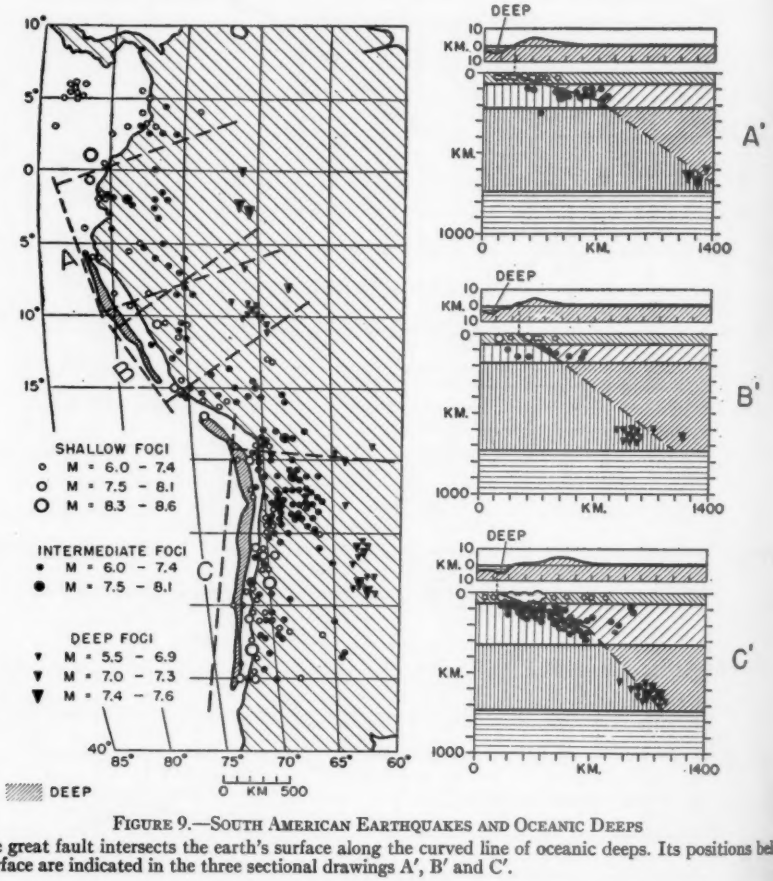


FIGURE 9.—SOUTH AMERICAN EARTHQUAKES AND OCEANIC DEEPS

The great fault intersects the earth's surface along the curved line of oceanic deeps. Its positions below the surface are indicated in the three sectional drawings A′, B′ and C′.

they have depths in excess of 8 km. Unlike the Tonga-Kermadec fault, the surfaces of this fault do not form a single plane. They can be thought of as a plane which has been bent and somewhat twisted along the long axis and bent along the short axis near the middle. It was necessary to make three sectional projections in order to display the three-dimensional distribution of the foci. Thus A', B', and C' are the three vertical sections taken perpendicular to the lines A, B, and C respectively of the map parallel lines on the map. In these profiles the vertical scale is 10 times that of the horizontal scale. In this region the observational uncertainty in the position of the hypocenters is about 100 km. in any spatial direction. It may be assumed therefore that the lines drawn through the projected positions of the hypocenters in A', B', and C' (Fig. 9) represent the projections of the fault surface. The hypocenters in this region are not distributed uniformly with respect to depth as they are in the Tonga-Ker-

adec area. North of Lat. 15½°S. the intermediate-depth foci form a continuous distribution over the depth range 70–200 km. South of Lat. 15½°S. the continuous distribution ends at a depth of 300 km. There are no foci in the depth range 300–600 km. The deep foci occur only at a depth of 550 to 660 km. The origin of this fault may be explained on the basis of an original configuration such as the one shown at *A* (Fig. 10) in which the continental mass had three layers and the oceanic mass two (or three) layers of different density. Thus δ_1 was greater than δ_2, and δ_3 was greater than δ_4. The constants δ_1 and δ_3 may have been equal. In any case the inequality between δ_1 and δ_2 must have been greater than that between δ_3 and δ_4 to provide for the shallower slope of the fault in the 70–300 km. depth range. To account for the bend in the long axis of the fault it may be assumed that the inequality between δ_1 and δ_2 varied along the length of the fault; it was greatest north of Lat. 15½°S. and approximately constant south of that parallel of latitude. The inequalities in densities may have been due in part to temperature differences resulting from different rates of generation of radioactive heat energy. The total length of the fault is approximately 4500 km. (2700 mi.). Its transverse dimension which dips under the continent is approximately 900 km., and it extends to a depth of approximately 690 km.—more than one tenth of the radius of the earth. The long line of oceanic deeps which parallel the western coast of the continent was formed by the downwarping of the oceanic block of this great fault, and the upwarping of its continental block produced the Andes Mountains.

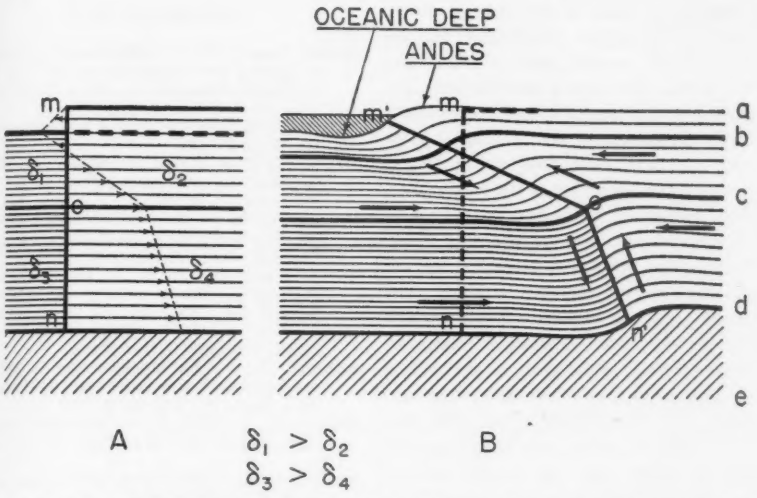


FIGURE 10.—SKETCH ILLUSTRATING PROPOSED ORIGIN OF THE GREAT SOUTH AMERICAN FAULT

OTHER DEEP-FOCUS SEQUENCES

A preliminary examination of a number of other deep-focus earthquake sequences which are associated with oceanic deeps indicates that they may all be generated on great faults similar to those described in this paper. Among these may be mentioned the Aleutian sequence, another one which extends from Southern Japan to Kamchatka, several sequences in the East Indies, the Central American sequences, and the West Indies sequences.

TSUNAMIS AND THE GREAT FAULTS

The characteristic movements of the great faults involve fairly large vertical components. It may be assumed, therefore, that a seismic sea wave or tsunami is generated whenever an earthquake focus on one of these faults is suffi-

ciently shallow to allow the faulting movement to reach the upper surfaces of the fault blocks where it can effect a sudden vertical displacement of the ocean floor. Moreover, the epicenter does not necessarily have to be situated within the areas of the oceanic deeps, since faulting or strain adjustment can be propagated up to several hundred kilometers from the focus. The faulting speed is finite and somewhat less than that of seismic waves (Benioff, 1938). Consequently the faulting impulse may arrive at the ocean floor up to several minutes after the beginning of the earthquake. The time of origin of the tsunami may thus be delayed with respect to the origin time of the earthquake. The sea waves generated by the upward movement of the oceanic block must begin with a rise in the water level, whereas those generated by the downward movement of the continental block must begin with a recession. Since the area of the ocean floor over the oceanic block is generally greater than that over the continental block the initial wave of recession is larger than the initial wave of advance. To an observer on the oceanic side of the fault all tsunamis would begin with a recession. On the other hand, to an observer on the continental side, the initial wave of advance may be so small as to be unnoticed, and the tsunami would thus appear to begi with a recession also. Presumably this accoun for the fact that most tsunamis are observe to begin with recessions.

References Cited

Benioff, Hugo (1938) *The determination of the extent of faulting with application to the Long Beach earthquake*, Seismol. Soc. Am., Bull., vol. 28, p. 77–84.

Griggs, David 2939) *The creep of rocks*, Jour. Geol. vol. 67, p. 25–251.

Gutenberg, Beno (1945) *Magnitude determination for deep-focus earthquakes*, Seismol. Soc. Am. Bull., vol. 35, p. 117.

——— (1948) *On the layer of relatively low wave velocity at a depth of about 80 kilometers*, Seismol. Soc. Am., Bull., vol. 38, p. 121–167.

——— and Richter, C. F. (1942) *Earthquake magnitude, intensity, energy, and acceleration*, Seismol. Soc. Am., Bull., vol. 32, p. 143–191.

——— —— ——— (1949) *Seismicity of the Earth*, Princeton Univ. Press.

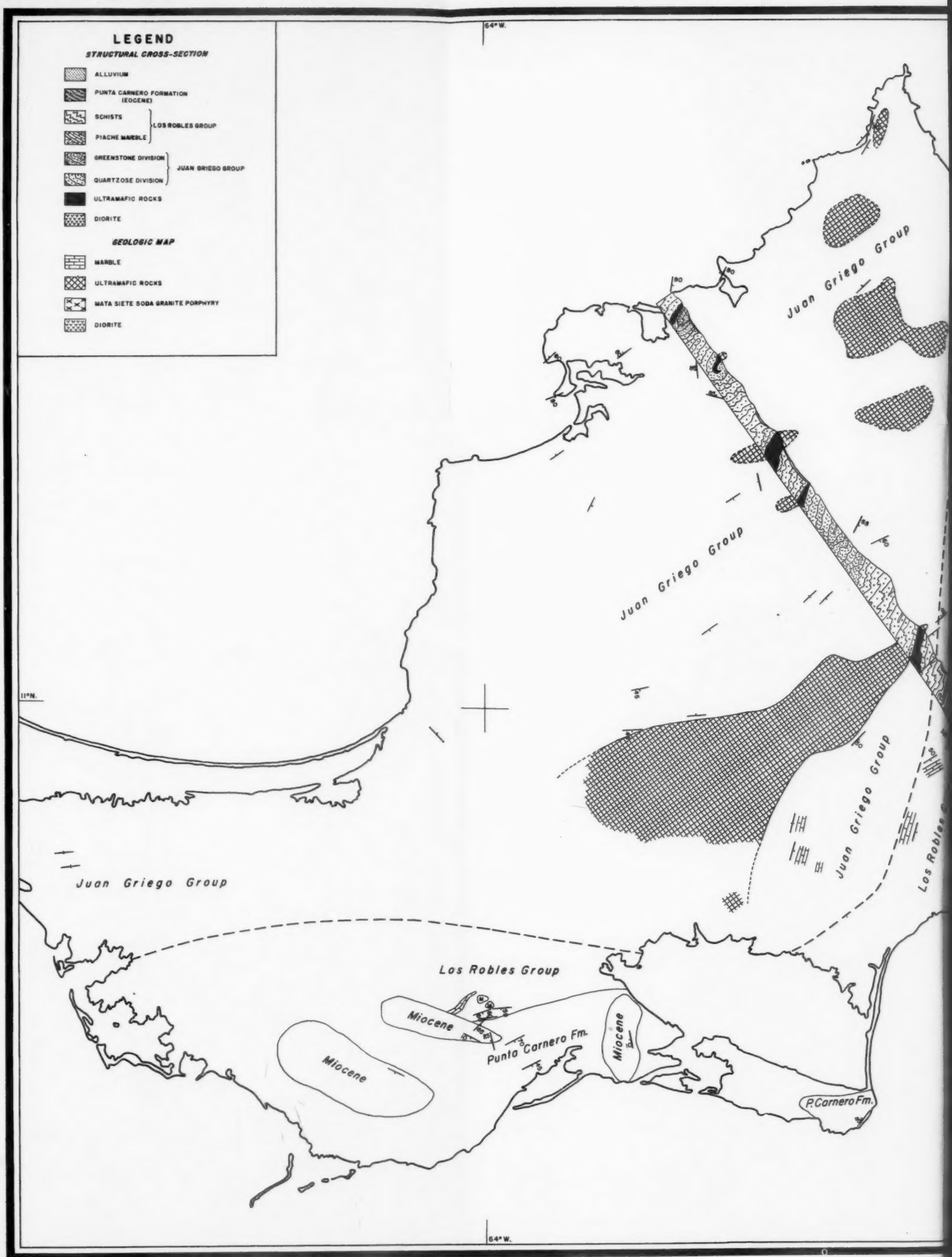
Lutts, C. E., and Himmelfarb, David (1940) *The creep phenomenon in ropes and cords*, Am. Soc. Test. Mat., Pr., vol. 40, p. 1251.

Richter, C. F. (1935) An instrumental magnitude scale, Seismol. Soc. Am., Bull., vol. 25, p. 1–32.

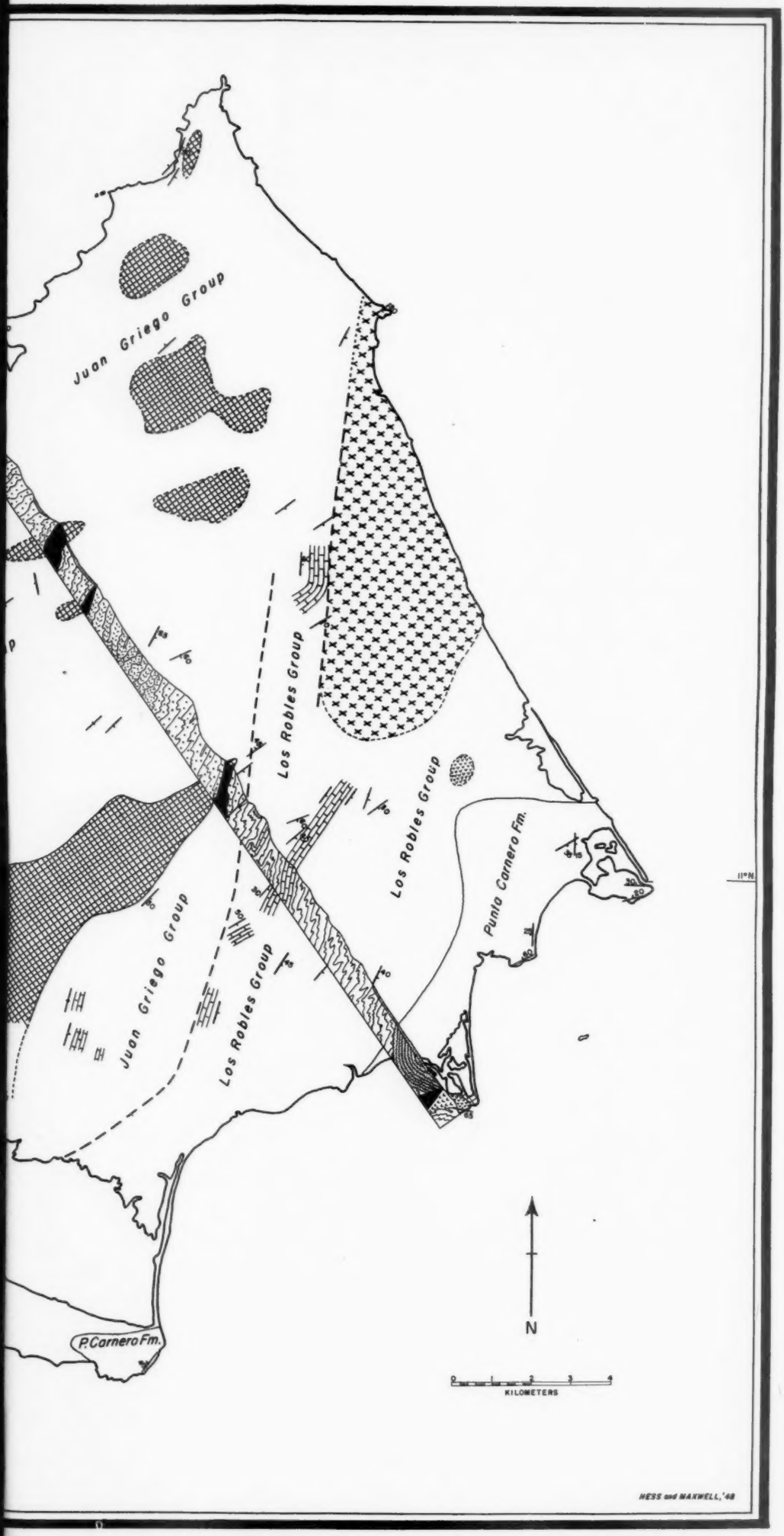
Seismological Laboratory, 220 N. San Rafael Ave., Pasadena, Calif.

Manuscript Received by the Secretary of the Society, July 8, 1949

Publications of the Division of Geological Sciences, California Institute of Technology, Pasadena, Calif. Contribution No. 505



GEOLOGIC SKETCH MAP OF EASTERN MARGA



EASTERN MARGARITA

GEO

Abstract
Introduc
Previous
Areal ge
Summ
Juan
Qua
Gre
Los R
Igneou
Ultr

Figure
1.—Sket
Te
2.—Sket
ph
tr
la

The
compose
and gra
amphibo
A belt o
marble li
morphics
intrude t
grained
Siete is
conforma
strike no

Along
island E
are folde
lain unc
Miocene
rocks are

* Part
the Tert
Kugler a

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL 60, PP. 1857-1868, 2 PLS., 2 FIGS. DECEMBER 1949

GEOLOGICAL RECONNAISSANCE OF THE ISLAND OF MARGARITA, PART I*

BY H. H. HESS AND J. C. MAXWELL

CONTENTS

	Page
Abstract	1857
Introduction and acknowledgments	1857
Previous work and literature	1858
Areal geology	1858
Summary	1858
Juan Griego group	1859
Quartzose division	1859
Greenstone division	1859
Los Robles group	1860
Igneous rocks	1860
Ultramafic intrusives	1860
Pyroxene diorite or gabbro	1861
Mata Siete soda granite porphyry	1861
Younger volcanics	1862
Structure	1862
Tentative conclusions as a result of Margarita reconnaissance	1863
Age of metamorphic rocks of Margarita	1863
Appendix	1866
Southeastern Caribbean area: speculations and working hypotheses	1866
References cited	1867

ILLUSTRATIONS

Figure	Page
1.—Sketch map of structural axes, faults, and Tertiary basins	1864
2.—Sketch map showing relation of metamorphism and ultramafic igneous rock intrusion to tectonic lines developed in late Cretaceous orogeny	1865

Plate	Facing page
1.—Geologic sketch map of eastern Margarita	1857
2.—Topographic base map of eastern Margarita	1868

ABSTRACT

The Island of Margarita, Venezuela, is largely composed of crystalline rocks, mainly garnetiferous and graphitic schist and gneiss, greenstone and amphibolite, intruded by peridotite and serpentinite. A belt of graphitic sericite schist with interbedded marble lies south and east of the higher-grade metamorphics. Small bodies of pyroxene diorite or gabbro intrude the sericite schist. The large mass of coarse-grained soda granite porphyry forming Cerro Mata Siete is believed to underlie the sericite schist unconformably. For the most part the metamorphics strike northeast and dip steeply southeast.

Along the south and southeast margin of the island Eocene sandstone, shale, and conglomerate are folded in a general synclinal structure and overlain unconformably by patches of gently dipping Miocene sediments. Pebbles and cobbles of volcanic rocks are abundant in the lower beds of the Eocene section, though no source for such rocks is known on the island.

Major deformation and metamorphism in Margarita presumably occurred before the end of the Cretaceous, with renewed folding after the Eocene sediments were deposited and prior to the Miocene.

INTRODUCTION AND ACKNOWLEDGMENTS

A reconnaissance of the eastern and larger portion of the Island of Margarita was made by K. F. Dallmus, J. G. Manley, Jose Mas Vall, and Hess in the period July 8 to 13, 1939. H. Kugler, A. N. Dusenbury, Hess, and Maxwell again visited the island from August 30 to September 2, 1947. Macanao, the western portion of the island, was not investigated.

A large part of the cost of this field work was borne by the Creole Petroleum Company with which Dallmus, Dusenbury, and Mas Vall are associated. Through the courtesy of Dr. C. A. Blank, the Instituto Nacional de Obras Sani-

*Part II on the stratigraphy and paleontology of the Tertiary formations is being prepared by H. Kugler and P. Bronnimann.

tarias furnished transportation and surveying equipment in 1939, and board, lodging, and transportation in 1947. Research funds were allocated by Princeton University to carry out a part of the investigation. A grant to Hess by the American Philosophical Society covered his field expenses during the 1939 work. The funds for preparation of this manuscript were supplied by the Office of Naval Research as part of the work on a contract between that office and Princeton University for geological and geophysical investigations in the Caribbean region.

The writers are particularly indebted to Dr. C. Gonzales de Juana for field notes which he supplied in 1939, making it possible to visit critical localities in the few days available for the field work. Similarly Dr. P. I. Aguerrevere gave helpful advice from his experience on this island and on Coche to the south of it. We wish to thank Dr. C. Uribe and Sr. A. Rodriguez for their assistance in the field in 1939. Dr. Victor Lopez was most helpful in making arrangements for the 1947 field work, and we are indebted to Dr. C. A. Blank for the many courtesies extended to us during our stay on the island.

The Hydrographic Office, U. S. Navy, in 1940, furnished a coast-line chart and triangulation net made during a survey by the USS HANNIBAL. The U. S. Army Map Service supplied advance copies of an excellent new topographic map of the island, 1/25,000, for the 1947 field work.

PREVIOUS WORK AND LITERATURE

After the 1939 field work Dallmus and Hess prepared a manuscript but did not publish it. The material from that report is incorporated in the present paper with necessary modifications.

Rutten (1940b) summarized the early literature and described a large number of rocks collected on the island by Hummelinck. These rock descriptions and Hummelinck's strike and dip observations are used in this report to supplement the writers' observations. Richards (1943) collected and described Pleistocene fossils from the vicinity of Juan Griego on the north coast. Gonzales de Juana (1947) devoted considerable attention to Margarita in his general paper on regional relations in eastern Venezuela as did Liddle (1946) in his revised edition of *The geology of Venezuela and Trinidad*.

AREAL GEOLOGY

Summary

A belt of Eocene sediments having a general synclinal structure outcrops along the southern margin of the island, and patches of Miocene sediments unconformably overlie the Eocene in the area west of the Laguna de Maritas. The remainder of the island consists of metamorphic and igneous rocks. The metamorphic rocks comprise a higher-grade facies—the Juan Griego group—characterized by the presence of garnet, and a lower grade facies—the Los Robles group—in which sericite is the characteristic mineral (Pl. 1). The higher-grade facies outcrops over most of the central, western, and northern portions of the island. The lower-grade metamorphics form a fringe around the higher-grade schists on the south and east and are presumed to be separated from them by a major discontinuity, perhaps a fault of large displacement.

Serpentinized peridotites, the most abundant igneous rocks, form the main mass of the Cerros de San Juan, Chica, and Manzanilla. The oval-shaped area of the Cerro Mata Siete on the east coast is composed of altered soda granite porphyry. Small areas of sheared and somewhat altered, moderately coarse-grained pyroxene diorite or gabbro occur in the valley south of the Cerro Mata Siete, forming a small hill, and on the Morro de Punta Moreno east of the town of Porlamar. Fine-grained basalt or andesite dikes 2 feet and less in width intrude metamorphics between Juan Griego and La Playa on the north coast. Two small dark dikes cut Eocene sediments north of Punta Moreno.

Fossiliferous marine deposits of Pleistocene age lie on wave-cut terraces a few feet above sea level in the vicinity of Juan Griego (Richards, 1943). Similar occurrences were noted between Punta Galera and La Playa farther northeast. Marine terraces are also present on the east coast near the southern end of the Cerro Mata Siete. Coarse quartz gravels possibly representing remnants of post-Miocene

luvial fans cover a considerable portion of the w area south and west of Los Vagres.

Juan Griego Group

General statement.—The garnet-bearing schists nd gneisses assigned to the Juan Griego roup are well exposed along coastal cliffs, oads, and valleys throughout the northern nd western parts of the island (Pl. 1). Particularly good outcrops may be seen north and northeast of the town of Juan Griego on the northwest coast (Pl. 2). The group seems to be made up of two major divisions, basal quartzose rocks and overlying greenstones and amphibolites, believed to be metavolcanics.

Quartzose division.—Most of the area mapped as Juan Griego group is composed of rocks of the quartzose division. Quartz-graphite-hematite schists outcropping north of Juan Griego and in the Picos de Maria Guevara to the southwest are believed to be the oldest rocks of this division. Graphite-limonite-quartz schist exposed in a stream valley east of Barrancas may likewise represent these basal beds.

Above the graphite-hematite schists is a great thickness of graphitic quartz-mica schists and albite-mica gneisses which at present cannot be further subdivided. These rocks are excellently exposed along the coast just north of Juan Griego, in the hills to the northeast, and in valleys on the north and southeast flanks of the Cerros de San Juan.

Near the top of the quartzose division there appears to be another thick sequence of graphitic quartz schists and quartzite, but these also contain beds of greenstone which are interpreted as the forerunners of the overlying metavolcanic division. These beds were observed on the northwest coast 2 kilometers southwest of La Playa and along the road 1½ kilometers east of Altagracia.

The following are typical mineral assemblages of rocks of the quartzose division:

(1) Quartz-muscovite-graphite-hematite schist; some of hematite in form of spherules with radiating fibrous structure.

(2) Quartz-albite-muscovite gneiss with minor garnet, carbonate, chlorite, zoisite, pyrite.

(3) Muscovite-quartz-chlorite schist with minor garnet (partly chloritized), pyrite.

(4) Quartz-chlorite-muscovite schist with minor garnet, albite, carbonate, pyrite, leucoxene.

(5) Muscovite-chlorite-quartz-garnet-graphite schist.

(6) Quartz-muscovite-graphite-zoisite schist with abundant limonite.

(7) Albite-muscovite-quartz-biotite gneiss.

(8) Albite-quartz-biotite-clinozoisite gneiss, minor muscovite.

(9) Muscovite - quartz - albite - clinozoisite-hornblende schist.

(10) Finely banded graphitic quartzite.

Number 9, from the locality 2 kms southwest of La Playa, is interpreted as a metatuff bed within the graphitic schists.

Garnet is sparingly distributed in the rocks of this group wherever they outcrop. Graphite is quite common and locally abundant. The feldspar is largely albite and sodic oligoclase, most of it untwinned and difficult to distinguish from quartz. Orthoclase is rare, and microcline was not observed. Most of the chlorite crystallized as a late replacement mineral after the foliation developed. In many cases it replaces garnet. Yellow-brown rutile is a characteristic accessory mineral, and hematite, leucoxene, pyrite, apatite, brown tourmaline, black opaques, sphalerite, and chrysocolla were noted. Rutten (1940b) mentions chloritoid and sillimanite also, but these were not identified in our specimens.

The feldspathic rocks have sutured interlocking grain boundaries. Most of the quartz has a fine mosaic texture of cataclastic origin, though some of the larger grains persist, surrounded by envelopes of mosaic quartz. Some muscovite is present in nearly all the rocks. Biotite is much less abundant. Clinozoisite and zoisite occur as minor constituents in most specimens. Quartz veins are abundant in this group of rocks.

Greenstone division.—Rocks of this division, mainly greenstone schists and amphibolites, were observed only in the northern part of the island in the triangular area bounded by Otrabanda, Altagracia, and Manzanillo. A thick section of these rocks is well exposed along the road between Tacarigua and Otrabanda. Mas-

sive, dark-green hornblende schists and fine-grained gneisses make up most of this exposure. Lighter-colored masses of feldspar-hornblende gneiss appear to be sheets intruded parallel to the foliation of the darker rocks. Other good exposures may be seen on the coast at La Playa and along the trail a kilometer or so east of Altagracia.

The following mineral assemblages are typical:

(1) Albite-blue-green hornblende-clinozoisite schist with minor chlorite.
(2) Albite-clinozoisite gneiss with subordinate blue-green hornblende, epidote, quartz, and accessory zoisite and brown tourmaline.
(3) Hornblende-garnet amphibolite; accessory magnetite.
(4) Albite-hornblende-clinozoisite gneiss; accessory magnetite, rutile.
(5) Hornblende-clinozoisite-quartz-garnet-muscovite gneiss; accessory rutile, apatite.
(6) Hornblende-zoisite-albite-quartz gneiss; accessory leucoxene surrounding rutile remnants.

Most of these rocks belong to the albite-epidote-amphibolite facies, but a small proportion belong to the higher-grade amphibolite facies.

Los Robles Group

This group includes sericite-chlorite schist and phyllite, quartz-sericite-chlorite schist, micaceous sandstone, graphitic sericite schist, calcite-sericite schist, and marble. These rocks exhibit a very low grade of metamorphism, about the chlorite zone of Harker (1939, p. 209). Shearing stress was probably fairly strong, but the temperature of metamorphism low. Exposures of the schists may be seen in the low hills west of Los Robles and along the roads leading northward from Porlamar. Steeply dipping marble forms a ridge parallel to the Porlamar-La Ascuncion road and is responsible for the sharp hill known as El Piache 3 kms northwest of Porlamar. For convenience this unit is called the Piache marble. The sandy facies is well exposed below the base of the Eocene sediments 3½ kms southwest of Los Vagres.

The Piache marble is uniformly fine-grained and varies from white to gray and shades of pink and green. At a quarry 1 km northeast of El Piache the marble occurs in beds 1 to 3 feet thick in which all these colors are represented. Thin shaly partings between the original limestone beds have in part been converted to bright-green chlorite with a little actinolite. Lenses of fine-grained quartz in the centers of some of the beds are probably recrystallized chert. A green vanadium-bearing micaceous mineral occurs locally in fractures in the white marble. Structures suggestive of shell fragments occur in some beds, but nothing determinable was collected.

North and east of San Antonio vertical, highly contorted, gray to white marble is associated with coarse quartz-mica gneiss and garnet-mica gneiss. If we are correct in interpreting these rocks as equivalent to those of the Juan Griego group then marble also occurs somewhere within the quartzose division of this group. Marble was seen as float northeast of San Juan Bautista but has not been found elsewhere in the group.

The nature of the contact and the relative ages of the Juan Griego and Los Robles groups have not been definitely determined. In general the same kinds of source rocks are indicated for the Los Robles group and the quartzose division of the Juan Griego group in that the bulk of both are quartz-mica rocks. Graphite is widespread in both. On the other hand the Los Robles group seems to be more calcareous and to have little metavolcanic material. The Los Robles rocks are considered the time equivalents of at least part of the Juan Griego group, and the two groups are separated by a major discontinuity, presumably a large fault. The abrupt change in metamorphic facies suggests the fault hypothesis.

Igneous Rocks

Ultramafic intrusives.—Ultramafic igneous rocks, mostly serpentinites and partially serpentinized peridotites, are the commonest intrusives. They are apparently more resistant than most other rocks on the island, for many of the larger mountain masses are composed of ultramafic rocks. The largest body, forming the Cerros de San Juan, appears to be a sill about

1000 feet thick dipping 45° SE. The southeastern slope of this mountain is essentially the stripped upper contact of the sill. Most of these intrusions occur in the higher-grade schist, but the small mass on Punta Moreno appears to have intruded the lower-grade Los Robles rocks. The peridotites have been somewhat metamorphosed. Those at Punta Moreno for example have been affected by strong shearing with the development of the typical "fish-scale" structure so common in serpentinites. North of Manzanillo the ultramafics have been hydrothermally altered to talc-actinolite-chlorite assemblages along contacts with wall rocks. The ultramafic intrusions are pre-Middle Eocene, for chromite and enstatite derived from them are common in the heavy-mineral suites of the Punta Carnero sediments.

Petrographically most of these rocks are serpentinites consisting largely of antigorite in flaky or spikelike reticulate aggregates. Bastite pseudomorphs after pyroxene are sparingly present, and relics of olivine are common. The least-serpentinized rock found, collected on the north side of the Cerro Chica, consists of 25 per cent serpentine and 75 per cent olivine. Accessory chromite occurs in most specimens, but no concentrations of this mineral were seen or have been reported. A little asbestos is known from the rocks west of Santa Ana.

Magnesite, of the porcelaneous cauliflower type, is a common weathering product; deposits on the east side of Cerro Chico have been worked sporadically. Magnesite forms the surface of considerable areas of the plains south of San Antonio and is quarried for road metal northwest of Santa Ana. Traces of nickeliferous sulfide are present in much of the Eocene sandstone and graywacke, presumably deposited from ground waters. One might expect nickeliferous clays on the weathered slopes of the hills composed of ultramafic rocks.

The ultramafic intrusives are part of the circum-Caribbean peridotite belt discussed elsewhere by Hess (1938; 1939). Their age, previously thought to be Eocene, is now considered late Cretaceous (Maxwell, 1948).

Pyroxene diorite or gabbro.—On Punta Moreno and on a small hill protruding through alluvium of the valley south of Cerro Mata Siete occurs a coarse-grained mesocratic igneous rock resembling a normal diorite. Thin sections from the Punta Moreno outcrop show that the rock is made up of augite and completely saussuritized feldspar in variable amounts, with the feldspar generally dominant. The rock has been sheared, giving it a gneissic fabric. Augite crystals have been somewhat crushed by the shearing. A little pale-green actinolite and chlorite develop along some of the shear zones. The feldspar is white and opaque, with no indication of its original composition. A small amount of secondary albite or sodic oligoclase occurs with actinolite in some of the shear zones.

At Punta Moreno the "diorite" intrudes sericitic and calcareous schists and impure marbles of the Los Robles group. The schists have been contact metamorphosed over a width of 2 to 4 feet, with the development of a nearly pure epidote rock at the contact. A beach pebble collected near the contact is a thinly laminated schist of alternating pale-green and white layers. Epidote and pale-green actinolite make up the green layers, while the white ones consist mainly of intergrown quartz and sodic oligoclase. Leucoxene is present in moderate amounts. This rock is interpreted as a tuffaceous sediment (or low-grade schist) which has undergone contact metamorphism.

The age of the "diorite" is not known, except that it is younger than Los Robles schist. On Punta Moreno where "diorite" and serpentinite both outcrop the two are separated by a shear zone, and their relative ages are indeterminable. Throughout the Caribbean area, however, gabbro or diorite ordinarily is intruded after ultramafic rocks, and on this basis the Margarita "diorite" is presumed to be younger than the ultramafic rocks. Its highly sheared character indicates that the diorite is older than the Punta Carnero formation.

Mata Siete soda granite porphyry.—This rock consists largely of euhedral to subhedral plagioclase crystals in a matrix of cataclastic (mosaic texture) quartz. Many of the plagioclases are sheared and broken. They exhibit an exceedingly fine polysynthetic albite twinning which suggests an original composition in the neighborhood of sodic oligoclase. The cores show rhythmic zoning and are somewhat sericitized. The borders are clear albite, in part at least porphyroblastic, for they include blebs of

quartz. Ferro-magnesian minerals for the most part constitute less than 5 per cent of the rock; the small amounts present are altered to epidote, actinolite, or chlorite. Its petrographic features indicate that the porphyry was intruded at relatively shallow depth.

Whether the soda granite porphyry originally intruded what are now the low-grade schists or whether it lies unconformably beneath them was not definitely determined. Gonzales de Juana (1947) favored the latter hypothesis, and considering available evidence the writers are inclined to agree. No contact metamorphism could be noted in the marble and schists along its western margin though the relations here are somewhat complicated by the presence of a recently active fault along the contact.

Younger volcanics.—In this category are included the unmetamorphosed dikes which occur sparingly within the metamorphics and Eocene sediments, and the pebbles of volcanics found in the Punta Carnero formation.

Pebbles and cobbles of volcanic rocks are fairly abundant in the conglomeratic beds of the Punta Carnero formation at the type section and at the base of the Punta Ballena section. Angular blocks of igneous rocks also occur in the Los Vagres limestone member at the base of the Punta Carnero section.

In the Punta Carnero formation the volcanic rock fragments are well rounded to angular, mostly 1–2 inches in diameter but some as large as 6 inches. Most are aphanitic, light to dark gray or greenish gray, amygdaloidal or porphyritic, and quite fresh on unweathered surfaces. Thin sections of five of the pebbles show two to be dacites, one an andesitic feldspar porphyry, and two crystal tuffs, probably andesitic, which appear to have undergone slight thermal metamorphism. In one of the dacites the feldspar microlites are oriented in a well-defined flow structure.

The basal Los Vagres limestone member contains scattered volcanic fragments, some as angular blocks 3 or 4 inches long, but most much smaller. A thin section of one of the larger volcanic blocks shows it to be a medium-grained quartz diorite with a diabasic texture. Other pebbles not sectioned appear to be aphanitic dacites or andesites, much like those in the overlying conglomerates.

Dikes seem to be only sparingly present. A number were observed along the coast between Juan Griego and La Playa, and two thin, dark ones cut Eocene sediments on Punta Moreno. No others were found.

The one dike for which a sample is available has intruded intensely folded graphitic schist about 5 kms northeast of Juan Griego. This dike is about 2 feet thick and is a fine-grained, greenish-gray holocrystalline hornblende basalt. The lath-shaped feldspars are quite fresh, twinned, and strongly zoned, with an average composition about An_{60}. Augite forms scattered microphenocrysts and abundant small anhedral grains. Pleochroic brown hornblende is somewhat less abundant. Calcite-filled irregular-shaped cavities are present bounded by feldspar laths. Leucoxene makes up about 2–3 per cent of the rock.

The volcanic pebbles of the Punta Carnero formation may have been derived partly from dike rocks cutting the older schists, but this source is inadequate to supply either the volume or variety of volcanic pebbles in the conglomerates. Presumably a series of lava flows lay on top of the metamorphic rocks in what is now the northern part of Margarita. Rutten (1940b, p. 820) mentions a possibly volcanic suite from Los Frailes islands 10 miles east and slightly north of Cabo Negro, the northern tip of Margarita. The rocks are described as diabase, diabasic diorite, and quartz diorite porphyry apparently intrusive into [contact?] metamorphosed tuffs, now uralite-albite-prehnite rocks.

Structure

The rocks of Margarita are characterized by dominantly northeasterly strikes and steep southeasterly dips. The distribution of rock types, insofar as mapped, and local variations in dips and strikes indicate that the schists have been isoclinally folded and overturned to the northwest (Pl. 2), the folds plunging to the northeast. One major anticlinal axis apparently passes through the Cerros de San Juan, possibly extending westward through the Picos de Maria Guevara; another extends northeastward from the vicinity of Santa Ana, and a third brings the graphitic hematite schists to the surface northwest of Juan Griego. Under this inter-

tation the larger ultramafic masses lie in or ar the crests of anticlines. The areas of tavolcanics mapped at Tacarigua and in the La Playa-Pedro Gonzales area are believed to ccupy major synclinal axes.

Structures within the Los Robles group are imilar to those in the higher-grade meta-morphics. The two outcrops of marble separated by mica schist south of La Asuncion suggest repetition by folding or possibly by faulting, but aside from this area the limited data indicate monoclinal southerly and southeasterly dips.

The contact between the Los Robles and Juan Griego groups is locally parallel to regional strike, as at El Piache, but to the north the contact cuts across the strike at a high angle. There is a suggestion of drag folding in the limestone south of La Asuncion and south of La Fuente as though the contact were a large transcurrent fault along which the east side had moved southward and upward. Topography and deranged drainage in the La Fuente area indicate a large fault bounding the Cerro Mata Siete on the west; recent movement has been down to the west, but its straightness suggests that the fault originated as a strike-slip fracture.

Eocene sediments south and east of the Los Robles schist strike more or less parallel to the schist. Where observed south of Los Vagres, however, the contact is unconformable. The schist is drag-folded and exhibits variable strikes, averaging about east-west, with dips ranging from 70° N. to 50° S. The Los Vargres limestone, with fossiliferous clayey beds at its base, bevels the drag-folded schist, strikes N. 50° E., and dips about 85° S. Cobbles of dense black limestone, derived from thin beds within the schist just below the contact, are present in in the Los Vagres limestone.

The structure of the Eocene sediments is essentially synclinal. Southerly dips characterize the Punta Carnero and the northern part of the Punta Bellena Eocene sections, and northerly dips are found in the southern part of the Punta Ballena section and in the Punta Moreno and Punta Mosquito sections. The lower members of the Punta Carnero formation at the type section have nearly vertical dips, while in the upper members the dips average 45° to 50°.

Parallelism of structural features, evident in the pre-Oligocene rocks of Margarita, does not characterize the Miocene and younger sediments. Miocene rocks, mostly reef limestones, marls, and impure sandy limestones, lie unconformably on both Los Robles schists and Eocene sediments in the Punta Carnero area south of Los Vagres. The Miocene rocks have low to moderate southerly and southwesterly dips (0°–25°) and strike northwesterly.

Tentative Conclusions as a Result of the Margarita Reconnaissance

Age of metamorphic rocks of Margarita.—The age of the metamorphic sequence of the Caracas group has been a matter of controversy for many years. Karsten (1850; 1851; 1853) was the first to suggest a Cretaceous age for these rocks. However, until Aguerrevere and Zuloaga (1937; 1938) pointed out the similarity in lithology between the Cretaceous Rio Negro, Cogollo, La Luna, and Colon formations and the metamorphic sequence and Kehrer (1937) noted the probable transition from normal to metamorphosed Cretaceous sediments in the region of Barquisimeto, the metamorphic rocks were generally considered pre-Cretaceous. Many still hold to this opinion. Wolcott (1943) discovered the first fossils in the metamorphic sequence, but these were rather undiagnostic Mesozoic pelecypods. Recently Dusenbury and Wolcott (1948) reported a microfauna from the metamorphics 5 miles south-southwest of Capaya. The fossils are considered to have come from an equivalent of the Los Colorados phase of the Las Mercedes schist and are correlated with the Turonian portion of the La Luna and Querecual formations.

The metamorphic rocks of Margarita are presumably of about the same age as the Caracas group. They are overlain unconformably by Eocene sediments. The metamorphism cannot be younger than early Eocene and, considering evidence from other portions of the Caribbean region (Maxwell, 1948), most probably occurred before the end of the Cretaceous.

Equivalents of the greenstone subdivision of the Margarita metamorphics, considered by the writers to be metavolcanics, have thus far not been found in the Caracas metamorphic

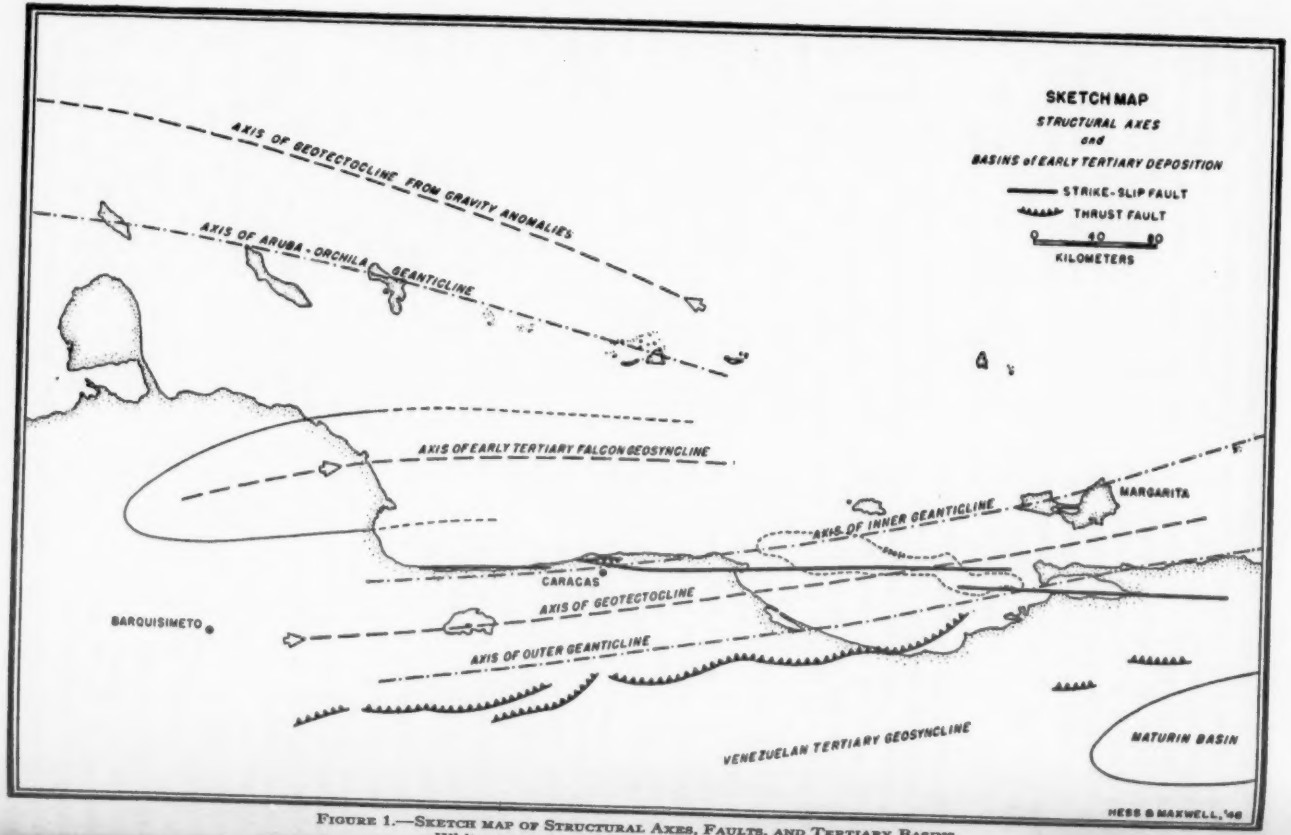


FIGURE 1.—SKETCH MAP OF STRUCTURAL AXES, FAULTS, AND TERTIARY BASINS
White arrows on axes indicate direction of plunge.

FIGURE 1.—SKETCH MAP OF STRUCTURAL AXES, FAULTS, AND TERTIARY BASINS
White arrows on axes indicate direction of plunge.

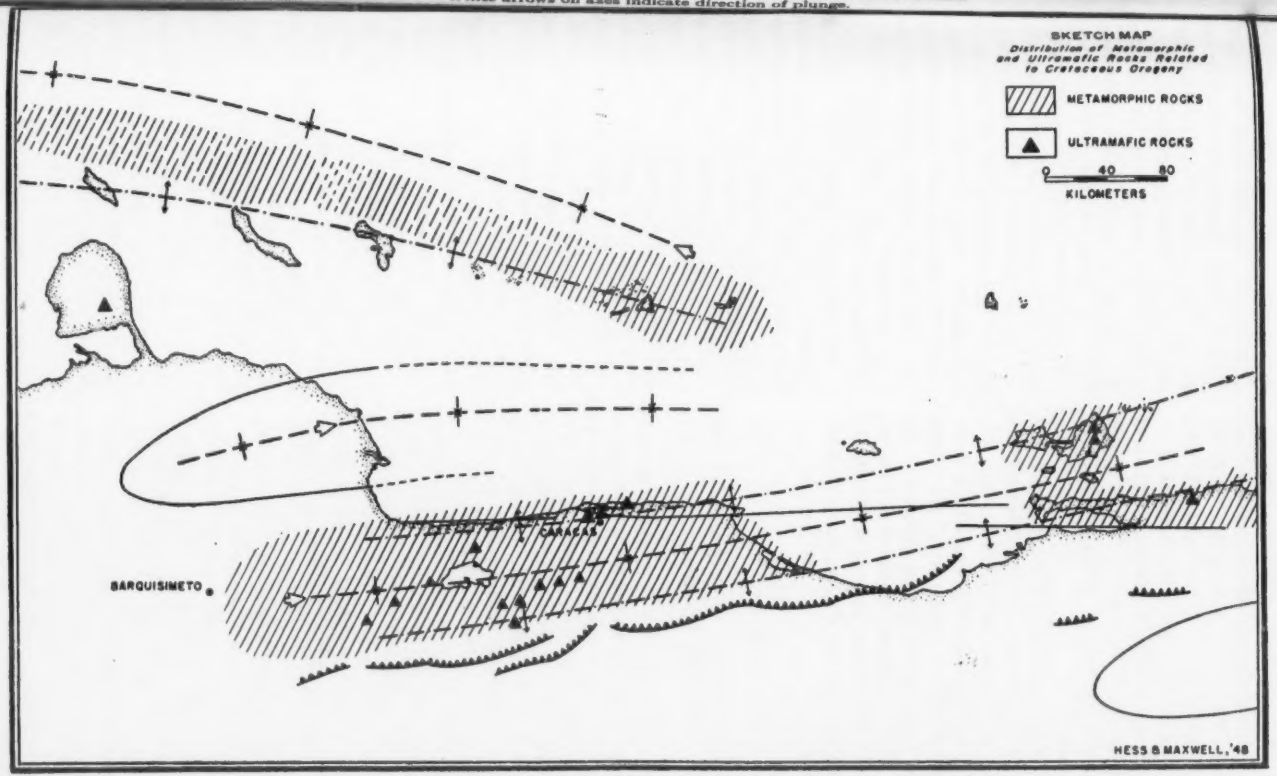


FIGURE 2.— SKETCH MAP SHOWING RELATION OF METAMORPHISM AND ULTRAMAFIC IGNEOUS ROCK INTRUSION TO TECTONIC LINES DEVELOPED IN LATE CRETACEOUS OROGENY
Metamorphics north of Aruba-Bonaire arc postulated because of their occurrence as pebbles in younger conglomerates on Bonaire and Curaçoa.

section. The greenstone subdivision is thought to be equivalent to the metavolcanics of Tobago (Maxwell, 1948) and the similar rocks of Puerto Rico, Hispaniola, and Cuba. The volcanic basement rocks of the Dutch Leeward Islands, Aruba, Curacao, and Bonaire might also be cited as equivalents. In the above islands much of the greenstone is considered to be late Cretaceous.

The volcanic activity in Margarita probably continued beyond the epoch of metamorphism, resulting in a series of volcanics above the schists, the erosion of which supplied the abundant pebbles and a good part of the clastic material found in the Eocene deposits of the island. These might be considered the equivalent of the Tobago unmetamorphosed volcanics and may be very late Cretaceous or possibly early Eocene.

Appendix

Southeastern Caribbean Area: Speculations and Working Hypotheses

Because of its location (Fig. 1) the geology of Margarita is important to an understanding of the tectonics of the southeastern Caribbean. More detailed information is needed from the island and adjacent areas. An examination of the gross tectonic features of the region will, however, be helpful in understanding the problems and in guiding future investigations.

There are many opinions as to the mechanism of mountain building. If it is agreed that island arcs were an early stage in the development of many mountain systems, the theories must explain not only the surficial aspects of mountain systems, but also the major gravity anomalies associated with island arcs. The downbuckling hypothesis of Vening Meinesz rather successfully fulfills these conditions.

A belt of large negative gravity anomalies lies north of the island chain extending from Aruba to Orchila (Fig. 1), apparently dying out northwest of Margarita. Another negative anomaly belt is found east of the Lesser Antilles arc, its axis passing over the island of Barbados (Hess, 1938). The anomaly belt broadens and becomes indistinct in the area of Trinidad and Tobago, but the east-west mountains of Trinidad and northern Venezuela as far west as Barquisimeto seem to be a structural continuation of the negative strip. As a working hypothesis it is suggested that the two negative gravity strips represent axes of downbuckling that tectonic forces are still active in the belt north of Aruba and the portion of the other belt east of the Lesser Antilles, but have died out on the westward continuation of the latter belt in the region of the Venezuelan coast, where that this area has risen and been deeply eroded. Structures equivalent to those submerged along the belt of strong negative anomalies are thus available for study in northern Venezuela, Margarita, and northern Trinidad. We believe that such a study will give valuable information as to the nature and mechanism of formation of Alpine-type mountain systems.

The position of Margarita in the regional framework is indicated in Figure 1. Figure 2 shows the distribution of metamorphic rocks largely metasediments but including some metavolcanics. They are thought to be mostly of Cretaceous age but perhaps include some older rocks (Jurassic in northern range of Trinidad and possibly in Venezuelan Cordillera de la Costa). The "Sebastopol granite" of Aguerrevere and Zuloaga (1937), lying unconformably beneath the metasedimentary schists and gneisses, may well be considerably older. The metamorphic rocks are confined to a long, relatively narrow strip which appears to be a prolongation of the negative anomaly belt and hence may be regarded as the geotectoclinal zone[1]. The metamorphism is probably related largely to the original buckling though some of it may be due to later deformations of the same belt and to phenomena associated with younger intrusions. The buckling and most of the metamorphism is thought to have occurred approximately at the end of the Senonian.

The distribution of ultramafic intrusives is shown in Figure 2. These occur only in and immediately adjacent to the geotectoclinal zone and commonly are distributed in two parallel belts along the margins of that zone. They were intruded immediately following the first buckling of the crust and did not recur during later major deformations of the same belt (Hess,

[1] The *geotectoclinal zone* is the strongly deformed belt immediately over the downbuckle of the crust, or *tectogene* (Hess, 1938).

9)). The axis of the geotectoclinal zone parently runs slightly diagonal to the present st line. It lies between Margarita and the stern segment of the Venezuelan Cordillera de Costa to the south. It enters the mainland r Higuerote and continues westward between e Cordillera de la Costa and Serrania del terior to Lake Valencia and beyond toward arquisimento.

Another characteristic feature of the geotectoclinal zone is thrusting and outward overturning of folds in both directions away from e axis. The northward overturning in Margarita on the north side of the axis and southward overthrusting along the Serrania del terior, south of the axis, are examples of this elationship. The lack of mapping of the Cordillera de la Costa makes it impossible to be ertain that the relationship persists there but e as yet unpublished work of G. Dengo in the icinity of Caracas is consistent with it. Kugler ral communication) reports northward thrusting along the southern margin of the Falcon asin.

The coast line and Cordillera de la Costa ake an angle of about 15° with the regional trikes. These topographic features are controlled in their trend by large faults, in part thought to be of strike-slip displacement.

The Eocene basin in which the Punta Carnero ediments were deposited may have extended long the axis of the geotectocline to Lake alencia and beyond. The Scotland beds of arbados lie in a homologous structural position nd bear some lithologic resemblance to the unta Carnero formation. The two are of pproximately the same age and have been eformed to a comparable extent by late or ost-Eocene movements.

The geotectoclinal zone is flanked to the orth and south by geanticlines (Fig. 1). South f the southern geanticline lies the great Venezuelan Tertiary geosyncline, containing an immense thickness of clastic sediments. North of the northern geanticline lies another early Tertiary geosyncline, the Falcon basin. It has a hinge thickness of Eocene and Oligocene clastics. This basin plunges eastward beneath the waters between the Cordillera de la Costa and the Aruba-Orchila arc. If the trough extended as far eastward as Margarita it should lie north of that island.

It should be noted that geosynclinal troughs did not develop in the southern Caribbean region until after the crust buckled. Over the entire area under discussion and far beyond its confines deposition of early Cretaceous arenaceous sediments was followed in middle Cretaceous by slowly deposited widespread limestones and shales (Cogollo, La Luna, Colon formations and equivalents). Unless the definition of a geosyncline is broadened to mean any area of marine deposition no geosyncline existed at that time. Accompanying the formation of the crustal buckle, parallel troughs developed, and into them flowed rapidly great volumes of poorly sorted clastic sediments with thicknesses measurable in tens of thousands of feet. These troughs are geosynclines in the sense of James Hall's original concept. The buckling certainly was not localized by a pre-existing geosyncline, but on the contrary the forces producing the buckling of the crust developed the troughs, and areas locally elevated by the deformation provided the source for the abundant clastic sediments which filled the troughs.

References Cited

Aguerrevere, S. E., and Zuloaga, Guillermo (1937) *Observaciones geológicas en la parta central de la Cordillera de la Costa, Venezuela*, Geol. y Min., Bol. T. 1, nos. 2, 3, 4, p. 8–24.

——— — ——— (1938) *Nomenclatura de las formaciones de la parte central de la Cordillera de la Costa*, Geol. y Min., Bol. T. 2, nos. 2, 3, 4, p. 281–284.

Dusenbury, A. N., and Wolcott, P. P. (1948) *Cretaceous metamorphics in the Coast Range of Venezuela*, Paper presented before Caracas Geologic Society, November.

Gonzales de Juana, Clemente (1947) *Elements of diastrophic history of northeastern Venezuela*, Geol. Soc. Am., Bull., vol. 58, p. 689–702.

Harker, Alfred (1939) *Metamorphism*, Methuen and Co., Ltd., London, 362 p.

Hess, H. H. (1938) *Gravity anomalies and island arc structure with particular reference to the West Indies*, Am. Philos. Soc., Pr., vol. 79, no. 1, p. 71–96.

——— (1939) *Island arcs, gravity anomalies and serpentinite intrusions; A contribution to the ophiolite problem*, 17th Inter. Geol. Cong., Rept. 2, 263–283.

Karsten, H. (1850) *Bietrag zur Kentniss der Gesteine des nordlichen Venezuela*, Deutsch. Geol. Gesell., Zeit., 2, p. 345–361.

——— (1851) *Ueber die geognostichen Verhaltnisse der nordlichen* Venezuela, Archiv. Min. Geogn., Bergbau Hutten., 24, p. 440–479.

——— (1853) *Die geognostichen Verhaltnisse der Ebenen Venezuelas*, Archiv. Min. Geogn., Bergbau Hutten., 25, p. 419–435.

Kehrer, L. (1937) *Algunas Observaciones en capas Cretáceas y pre-Cretáceas de las partes suroeste y central de Venezuela*, Geol. y Min., Bol. T. 1, nos. 2, 3, 4, p. 49–73.

Liddle, R. A. (1946) *The geology of Venezuela and Trinidad*, Paleont. Research Inst., Ithaca, New York, 890 p.

Maxwell, J. C. (1948) *Geology of Tobago, British West Indies*, Geol. Soc. Am., Bull., vol. 59, p. 801–854.

Richards, H. G. (1943) *Pleistocene mollusks from Margarita Island, Venezuela*, Jour. Paleont., vol. 17, p. 120–123.

Rutten, L. (1940a) *New data on the smaller islands north of Venezuela*, Nedarl. Akad. v. Wetten schappen, vol. 43, no. 7, p. 820–827.

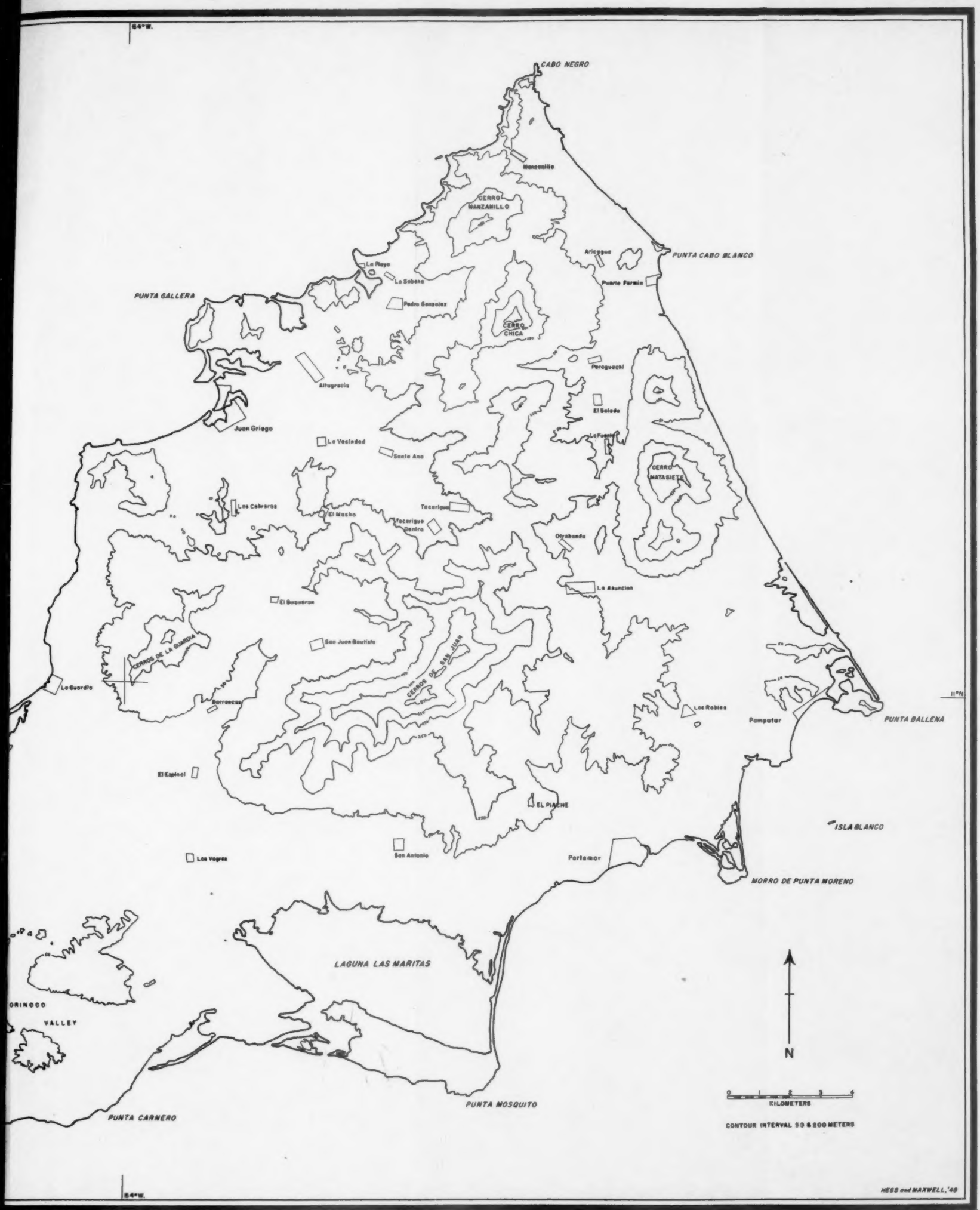
——— (1940b) *On the geology of Margarita Cubagua and Coche (Venezuela)*, Nederl. Akad. v. Wettenschappen, vol. 43, no. 7, p. 828–841.

Wolcott, P. P. (1943) *Fossils from metamorphic rocks of Coast Range of Venezuela*, Am. Assoc. Petrol. Geol., Bull., vol. 27, p. 1632.

PRINCETON UNIVERSITY, PRINCETON, N. J.
MANUSCRIPT RECEIVED BY THE SECRETARY OF THE SOCIETY, FEBRUARY 3, 1949.
PRINCETON INVESTIGATIONS OF CARIBBEAN GEOLOGY, NO. 2.

TOPOGRAPHIC BASE MAP OF EAS

Compiled from U. S. Army Map Service 1/25



TOPOGRAPHIC BASE MAP OF EASTERN MARGARITA

Compiled from U. S. Army Map Service 1/25,000 sheets.

HNOLOGY DEPARTMENT

BULLETIN

OF

The Geological Society of America

PUBLIC LIBRARY
JAN 31 1950
DETROIT

VOLUME 60

NUMBER 12 Part 2

DECEMBER 1949

UBLISHED MONTHLY BY THE SOCIETY

COUNCIL

President

WILLIAM W. RUBEY, Washington, D. C.

Past President

CHESTER R. LONGWELL, New Haven, Conn.

Vice-Presidents

CHESTER STOCK
Pasadena, Calif.

ROBERT B. SOSMAN
Westfield, N. J.

WINIFRED GOLDRING
Albany, N. Y.

JOHN W. GRUNER
Minneapolis, Minn.

Secretary

H. R. ALDRICH, 419 West 117 Street, New York, N. Y.

Treasurer

J. EDWARD HOFFMEISTER, Richester, N. Y.

Councilors

(Term expires 1950)

GEORGE M. FOWLER
Joplin, Mo.

F. J. PETTIJOHN
Chicago, Ill.

EARL INGERSON
Washington, D. C.

(Term expires 1951)

JOHN W. AMBROSE
Toronto, Canada

S. W. MULLER
Stanford University, Calif.

THOMAS B. NOLAN
Washington, D. C.

(Term expires 1952)

E. F. DAVIS
Los Angeles, Calif.

J. HOOVER MACKIN
Seattle, Wash.

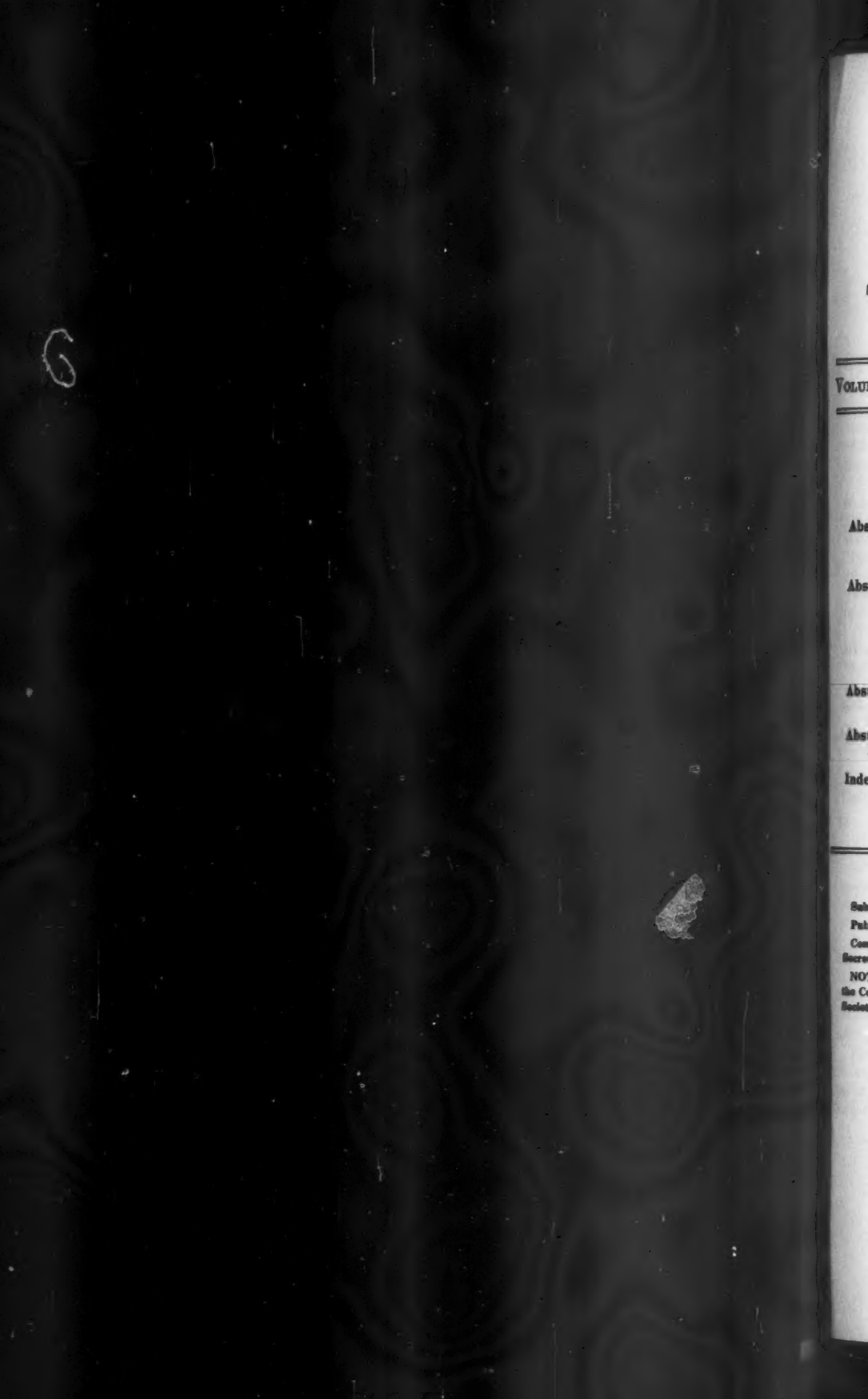
RICHARD J. RUSSELL
Baton Rouge, La.

COMMITTEE ON PUBLICATIONS

A. S. WARTHIN, JR., *Chairman*
K. K. LANDES
C. L. MOODY

H. R. ALDRICH, *Editor-in-Chief*
AGNES CREAGH, *Managing Editor*
} *Conferees*

BOOK



Bulletin

of

The Geological Society of America

VOLUME 60 December 1949 NUMBER 12, Part 2

CONTENTS

	Pages
Abstracts of papers presented at the meeting in El Paso, November 10–12, 1949 (Geological Society, Mineralogical Society, Paleontological Society, Society of Vertebrate Paleontology, and Society of Economic Geologists)	1869–1934
Abstracts of papers presented at the meeting in Berkeley, April 15, 16, 1949 Cordilleran Section of the Geological Society	1935–1948
Pacific Coast Branch of Paleontological Society	1949–1952
Seismological Society	1953–1958
Abstracts of papers presented at the meeting in Boulder, April 23, 1949 Rocky Mountain Section of Geological Society	1959–1966
Abstracts of papers presented at the meeting of Section E, AAAS, in New York, December 29, 30, 1949	1967–1978
Index to Volume 60 (July-December)	1979–1990

Subscription $15 per year.

Publication Office: Mt. Royal & Guilford Aves., Baltimore 2, Md.

Communications for publication should be addressed to The Geological Society of America, Dr. H. R. Aldrich, Secretary, 419 West 117th Street, New York 27, N. Y.

NOTICE.—Four weeks notice of change of address is necessary. In accordance with the rules established by the Council, claims for non-receipt of the preceding number of the Bulletin must be sent to the Secretary of the Society within three months of the date of the receipt of this number in order to be filled gratis.

Entered as second-class matter in the Post-Office at Baltimore, Md., under the Act of Congress of July 16, 1894.

Accepted for mailing at special rate of postage provided for in Section 1103 Act of October 3, 1917, authorized on July 8, 1918.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 60, PP. 1869-1990 DECEMBER 1949

ABSTRACTS OF PAPERS PRESENTED AT THE NOVEMBER MEETING IN EL PASO, NOVEMBER 10, 11, AND 12, 1949

SEDIMENTARY ROCKS OF PERMIAN AGE IN THE NORTHWESTERN MARFA BASIN, HUDSPETH COUNTY, TEXAS*

Claude C. Albritton, Jr. and J. Fred Smith, Jr.
3436 University Blvd., Dallas, Texas; U. S. Geological Survey, Denver Federal Center, Denver, Colo.

Little is known regarding the Permian stratigraphy of the Marfa Basin. Outcrops are few and scattered, and the subsurface geology is virtually unknown. Two isolated exposures are located in the Malone and Finlay mountains. The Finlay area is near the northern border of the basin, and the Malone area is farther south in the basin proper. Although these mountains are only 7 miles apart, the Permian rocks exposed in them are remarkably different.

In the Finlays the exposed Permian sequence measures 1600 feet thick and consists principally of clastic rocks. A detailed section shows 55 per cent siltstone, 25 per cent limestone conglomerate and pebbly limestone, and 20 per cent limestone of fine to coarse texture. Marine fossils are abundant, and well-preserved remains of terrestrial plants were found at one horizon.

In the Malones the exposed Permian measures 600 feet thick and consists principally of chemical precipitates. Gypsum is the predominant rock type, but there are many interbedded masses of limestone. Marine fossils have long been known to occur in the oldest limestone member; recently they have also been found in the youngest.

The fossils indicate that all the Permian in the Finlays and at least the lower part in the Malones belong to the Leonard series. Probably the deposits of the two areas were partly contemporaneous. Thus it appears that along the northern margin of the Marfa Basin contrasting sedimentary facies interfinger in the same complex manner as obtains along the western border of the near-by Delaware Basin.

STRUCTURAL FEATURES ASSOCIATED WITH LEAD AND ZINC ORES OF THE GOODSPRINGS DISTRICT, NEVADA*

Claude C. Albritton, Jr., Arthur Richards, Arnold L. Brokaw, John A. Reinemund, and David A. Phoenix
3436 University Blvd., Dallas, Texas (Albritton)

Although the Monte Cristo (Mississippian) limestone averages only 700 feet in thickness—roughly 6 per cent of the local stratigraphic column—it has produced 97 per cent of the combined lead and zinc output of the Goodsprings district. Compared with the other formations, it is on the whole more massive. Locally its upper limit is an irregular unconformity surface.

Deformation has extensively and complexly fractured the Monte Cristo limestone, but the thinly bedded units above and below remained relatively intact. The characteristic structural pattern of the Goodsprings district is one of imbricate thrust blocks divided into smaller blocks by high-angle faults. Mineralizing fluids rose along the high-angle faults; and in several mine areas it appears that the conduits were where fractures of different trends link without offset, or where differential movement created openings along arcuate faults.

The high permeability of the Monte Cristo limestone favored lateral spreading of fluids and replacement of the limestone by sulfides. In some places the paths of maximum permeability were partings between beds, or sandy fillings in old caves; more commonly they were zones of fractured ground along flexures or faults. Relatively impermeable bodies of mudstone and altered porphyry,

* Published by permission of the Director, U. S. Geological Survey.

as well as films of clayey gouge along thrust planes, locally contributed to formation of ore by retarding upward progress of fluids. Beneath some of these impermeable caps the ore remains unaltered; elsewhere it has been almost completely oxidized to depths below present mine workings.

LEUCOXENE PROBLEM*

Victor T. Allen
Dept. of Geology, Saint Louis University, St. Louis, Mo.

The author's interest in leucoxene began in 1934 during a study of the diaspore clays of Missouri. From 1939 to 1946 leucoxene was observed in bauxite and high-alumina clays. X-ray patterns were made by P. F. Kerr, W. F. Bradley, J. W. Gruner, and J. M. Axelrod, and electron micrographs were contributed by the U. S. Bureau of Standards. The laboratories of the U. S. Geological Survey and the Illinois State Geological Survey made chemical analyses of new leucoxene samples that formed in the following ways: as a coating on ilmenite from Norway, as a clay derived from lavas from Hawaii, as a clay at Andersonville, Ga., as a pocket-filling clay at Roseland, Va. Hydrotitanite from Arkansas and xanthitane from North Carolina were also analyzed. These analyses served as controls for the petrographic and X-ray studies.

The following conclusions resulted from these studies: (1) most of the opaque gray compound known to petrographers as leucoxene is amorphous; (2) the composition of leucoxene varies chemically and mineralogically; (3) X-ray patterns of leucoxene are similar to those of anatase, sphene, and rutile; (4) 1 per cent of well-crystallized sphene may show in an X-ray pattern, so it is not known if some X-ray patterns represent the bulk of the leucoxene sample or a few well-crystallized grains; (5) a small amount of water is present in many analyses of leucoxene; whether this water is combined as a hydrate of titanium oxide or is adsorbed on the smallest particles of an oxide of titanium is not established; (6) leucoxene should be retained as a petrographic term for the alteration product in which titania occurs in rocks, but it must not be used as a mineral name implying a definite mineral species.

OLDER PRECAMBRIAN STRUCTURE IN ARIZONA*

Charles A. Anderson
Box 633, Prescott, Ariz.

The older Precambrian rocks of Arizona include the Vishnu, Yavapai, and Pinal schists, all overlain unconformably by nonmetamorphosed younger Precambrian rocks. The older Precambrian schists, unnamed gneisses, and associated granitic masses crop out in many of the mountain ranges southwest of the plateau.

The stratigraphy and structure of the schists can be unraveled by detailed mapping, and work now in progress by the U. S. Geological Survey in the Bagdad, Prescott-Jerome, and Little Dragoon areas is revealing that folded structures, in general, trend northwest to northeast. Faults of Precambrian age are parallel to or transverse to the folds. Earlier work by Wilson in the Mazatzal Mountains revealed eastward-dipping low-angle thrust faults of Precambrian age.

In the Bagdad and Prescott-Jerome areas, a variety of igneous rocks, including rhyolite, alaskite porphyry, diorite, and gabbro, were intruded into the schists prior to the widespread invasion of granite.

Areas studied in detail show that the degree of metamorphism is variable and that some of the preintrusive rocks are nonfoliated, whereas others are highly schistose and locally sheared out into boudinage structure. Some of the intrusive rocks, including granite, show the effect of dynamic metamorphism. The grade of metamorphism is low except near the large masses of granite where coarse-grained sillimanite-bearing schists are found.

* Published by permission of the Director, U. S. Geological Survey.

AGE OF THE LAST PLUVIAL IN NEW MEXICO AND TEXAS

Ernst Antevs
The Corral, Globe, Ariz.

The disparity between the small Pleistocene glaciers and the large pluvial lakes (lakes Estancia, San Augustin, etc.) in New Mexico suggests that the glaciers and the lakes culminated at separate times. Primarily dependent on low temperatures, the glaciers probably attained their maxima about when the western ice sheet did so at Des Moines, Iowa. Judging from the glaciers the precipitation in New Mexico then was small, which is in accord with the long glacial winters and the light present winter precipitation.

Contrarily, the large pluvial lakes suggest heavier precipitation and more summer rains than now. They may therefore have attained their greatest volumes first when the Atlantic atmospheric high-pressure area, which was displaced southward during the glacial age, again moved sufficiently far north in summer to send masses of moist tropical air in over Texas and New Mexico, as it is doing at present. If the western glaciation culminated some 20,000 years ago and the temperature attained its present level about 9000 years ago, the relevant pluvial lakes reached their highest levels possibly some 12,000–10,000 years ago. A similar date for a long moist age is suggested by the Patschke bog, east of Austin, Texas, studied by Potzger and Tharp.

The age of this pluvial culmination is archaeologically important. For instance, the Folsom artifacts at Clovis, N. M., date from it, and the Sandia level in Sandia Cave, N. M. (Kirk Bryan), possibly just antedates the maximum.

PRE-*EQUUS* HORSES FROM GOLETA (MORELIA) MICHOACAN, MEXICO

A. R. V. Arellano and Ernesto Azcón
Apartado 8393 and Apartado 686, Mejico, D. F., Mexico

Goleta is in the eastern part of the Morelia (State of Michoacán) lacustrine basin, filled during Pliocene and possibly Lower Pleistocene time and dissected since then. Some 30 to 40 meters of presumably Pliocene diatomaceous, tuffaceous, and clayey sediments are exposed with the Tacubaya—weathering (or paedogenic) feature at the top. The Becerra bone-bearing formation of Central Mexico (Latest Pleistocene) is not conspicuously developed here as it is in the Mexico City Basin.

In 1948 Azcón collected horse teeth that had weathered out from a clay bed in the lacustrine series, 10 meters above a diatomaceous bed with proboscidean remains. In June 1949 Arellano and Azcón collected more horse teeth and studied the stratigraphy.

Dr. C. L. Gazin identified the teeth as *Nannipus cf. montezuma* (Leidy) and *Plesippus* sp. suggesting a Blancoan age. Dr. A. R. Stirton concurred in the first identification but thought that the second was more properly *Pliohippus* (*Astrohippus*) *cf. osborni* Frick and that the most likely level for them was Hemphillian. Dr. C. W. Hibbard points out that these two genera of horses range in Kansas up into the Meae formation (basal Pleistocene) and cannot be considered diagnostic of the Pliocene.

Stratigraphic evidence permits a Pliocene or a Lower Pleistocene age for this series. It is capped by the Tacubaya, referred to early Wisconsin by Bryan.

Previous references of Pliocene land fossils on the Central and Southern Mexican Plateau are meager and, for the most part, unauthenticated. Nearly all are based on mastodon, but one is based on horses as well (Tehuichila, or Zacualtipan), one on a rhinoceros (Valley of Toluca), and still another one on plants (Texuantla, Real del Monte).

MICROSCOPE AND REFRACTOMETER FOR INFRA-RED LIGHT

René J. Bailly and Kenneth A. Holke
Dept. of Geology, Washington University, Saint Louis, Mo.

In 1947 Bailly described a method of mineral determinations in infra-red light. The eyepiece of the microscope or refractometer is replaced by a photoelectric ocular, and the variations of the photo-

electric current, produced by the observed phenomena, can be read on a very sensitive galvanometer. Generally a current amplification is needed. The method is rather long and requires a precise reasoning.

Bailly has devised a new method, based on the same principles with the use of an electronic image converter tube as the main part of the ocular instead of an electric photocell.

The invisible infra-red image produced by the lenses of the microscope or refractometer is focused on the front, half-transparent cathode of the tube. Inside the converter, a set of electronic lenses bundles the beam of electrons coming from the cathode and focuses them on a fluorescent screen, producing a visible image of the observed field. This image, whose definition is very high, is magnified by an optical device. In this process, neither galvanometer nor amplifier is needed. The high voltage is supplied to the electronic lenses by a small power unit.

Use of the microscope and refractometer in infra-red light is exactly similar to their use for studies in visible light.

Among several researches, the variation of refractive index with the chemical composition is studied for the spinels and particularly for the family of chromite.

GEOLOGICAL AND BOTANICAL STUDY OF THE BRANDON LIGNITE AND ITS SIGNIFICANCE IN COAL PETROLOGY

Elso S. Barghoorn
Biological Laboratories, Harvard University, Cambridge, Mass.

Although virtually unknown in the northeastern United States, Tertiary strata occur in limited areas in western New England. By far the most significant of these Tertiary horizons is a small area at Brandon, Vermont.

Lignite, of Mid- or early Tertiary age, associated with kaolin, ocher, and the oxide ores of iron and manganese occur here in close proximity in a very restricted area. The recognizable plant tissues in the lignite consist entirely of the remains (fruits, seeds, pollen, and wood) of hardwood trees and shrubs. No coniferous woods have been found. The deposit is devoid of bedding planes, yet is composed primarily of water-transported plant fragments, admixed with quartz pebbles and sand. Structural preservation of the constituent plant tissues is exceptionally good, permitting detailed anatomical study and accurate identification of the plant components of the lignite. In addition to wood fragments and attritus the Brandon deposit is featured by the abundance of well-preserved fruits and seeds. The total flora of the lignite comprises over 100 species, of which approximately one-fourth have been botanically determined. Analyses of discrete plant fragments have been made with reference to the anatomical, physical, and chemical changes which occur during lignitization. These studies have provided new analytical data and further understanding of the complex processes which feature the transformation of plant tissues into coal.

SIMPSON GROUP, WEST TEXAS AND SOUTHEASTERN NEW MEXICO

Jerald H. Bartley
University Lands, Midland, Texas

The Joins, Oil Creek, McLish, Tulip Creek, and Bromide formations (oldest to youngest) constituting the Simpson Group of the Middle Ordovician, are present in the subsurface conforming in areal extent to that portion of the Permian Basin of West Texas and Southeastern New Mexico, which contains the Midland Basin, Central Basin Platform, and the Delaware Basin. In Simpson time this area was one large basin that received sediments attaining a known thickness of 2000 feet (northwest Pecos Co., Texas), with isopach determinations indicating a thicker section in the trough of this basin (west-central Pecos Co., Texas) which can only be confirmed by deep exploratory drilling. The nearest known outcrops of the Simpson occur in the Arbuckle and Wichita mountains of Oklahoma, the Marathon and Solitario regions of Trans-Pecos (western Texas), and southern Colorado.

Deeper drilling will be necessary before a complete study of the subsurface conditions in the western half of this Simpson basin can be made; however, sufficient subsurface data make possible the correlation of the Simpson formations throughout the eastern half of the basin, showing progressive thinning of these formations from the trough toward the periphery of the basin. The McLish and the Oil Creek disappear by overlap, and the Bromide is absent due to nondeposition near the periphery of the eastern half of the basin.

Isopach studies of the Simpson group show that all the present known Ellenburger (lower Ordovician) structures in West Texas and Southeast New Mexico, now covered with sediments of Simpson age, were present during Simpson deposition.

GEOMORPHIC EVENTS OF EAST-CENTRAL MEXICO*

Chas. H. Behre, Jr., and Carl Fries, Jr.
Columbia University, New York, N. Y.; U. S. Geological Survey, Mexico, D. F., Mexico

This discussion is presented to arouse interest in Mexican geomorphology. The region described is an irregular five-sided area with the cities of Monterrey, Tampico, Jalapa, Queretaro, and San Luis Potosi at the vertices. The fairly even-topped Sierra Madre Oriental terminates eastward in an abrupt escarpment overlooking the low coastal plain. Its most impressive structures are close folds with sinuous axes, which are well exposed between Monterrey and Tamazunchale. These magnificent folds are truncated by two well-marked erosion levels 500 feet apart, beginning 500 feet above the rims of remarkable canyons (Moctezuma, Nautla, Guayalejo) that head westward in broad, old-age valleys underlain by extrusive rocks and conglomerate. Limestone areas of the upland are characterized by karst topography with many great sinks (Jacala, Dulces Nombres, El Doctor region) elevated far above present base level. These were formed during a pre-Recent cycle, and their reddish soils are now partly dissected or are being covered by gravel. East of the Sierra escarpment are mesas capped by gravel and basaltic lava (Highway 1, Ciudad Victoria to El Limon), cut by trenches partly filled with gravel (Highway 1, north of Llera, Tamaulipas).

These facts and known coastal-plain Tertiary marine sedimentation suggest these major events: (1) probably middle Eocene to late Oligocene(?) folding, uplift, intrusion, volcanism, coastal-plain marine sedimentation; (2) probably early Miocene(?) to middle Pliocene(?) repeated uplift, intrusion, volcanism, alluviation and marine sedimentation, erosion to low relief at near base level; (3) probably late Pliocene(?) and early Pleistocene(?) uplift, faulting, volcanism, renewed erosion; (4) Pleistocene and Recent basaltic volcanism, faulting, active erosion, some alluviation.

GOLDEN VALLEY FORMATION OF NORTH DAKOTA*

William E. Benson
U. S. Geological Survey, General Geology Branch, Denver, Colo.

In 1947 the discovery of specimens of the floating fern, *Salvinia preauriculata*, demonstrated that beds of Eocene age underlie part of southwestern North Dakota. The name Golden Valley formation was suggested for these beds, for a town near the type locality. Since 1947, remnants of the formation have been mapped over much of the southwest quarter of the State.

The Golden Valley formation has two members. The distinctive lower member consists of purplish-gray carbonaceous shales interbedded with white sandy kaolinitic clays commonly stained bright yellow orange on outcrop surfaces. The upper member consists largely of fine- to coarse-grained micaceous sands and silts with small clay lenses.

The Golden Valley formation is essentially conformable with the underlying Tongue River member of the Fort Union formation and disconformable with the overlying White River group. In places, pre-Oligocene erosion removed the entire Golden Valley formation before the White River sediments

* Published with the permission of the Director, U. S. Geological Survey.

were deposited. Regional relations of the White River group suggest that the uplift responsible for this erosion was greatest in the Black Hills area and diminished northward.

Agreeing with R. W. Brown that the Sentinel Butte shale is only a facies of the Tongue River member of the Fort Union formation and is therefore of Paleocene age, the author places the Paleocene and Eocene boundary between the Tongue River member and the Golden Valley formation.

The lower member of the Golden Valley contains ceramic clays and also is the most reliable horizon for mapping regional structure in southwestern North Dakota.

FOSSIL PLANTS FROM SANTEE VALLEY, SOUTH CAROLINA

E. W. Berry
Dept. of Geology, Duke University, Durham, N.C.

Thick beds of fossil leaves have preserved numerous complete leaf remains which can be floated from the bulk and mounted in balsam. Some two dozen species have been found. The oaks are the most abundant, and they show much variation. The beds are probably of Pleistocene age. The flora gives evidence of mixed hard woods with a climate little different from that in the same latitude today.

STRUCTURE OF THE PRECAMBRIAN, DENVER MTN. PARKS QUADRANGLE, COLORADO

Margaret Fuller Boos
2036 South Columbine St., Denver, Colo.

The framework of the Denver Mtn. Parks Precambrian consists of structures developed by at least four generations of closely related and interpenetrated siliceous igneous rocks—*i.e.*, monzonite gneiss (Santa Fe Mtn.), Boulder Creek granite (Mt. Evans), Pikes Peak granite (Rosalie lobe), and Indian Creek plutons (Silver Plume granite)—that are invasive in the paragneisses and schists of the Idaho Springs formation and the metagneisses and schists of the Swandyke ? formation.

Close folding of the country rock, which preceded and accompanied the intrusions, established a widespread northwest-southeast structural pattern throughout the area.

Earliest faults trend northwest-southeast, and the rocks involved are strongly sheared. Many of the faults of the Central Mineral Belt to the north and west extend across this quadrangle. Later faults strike east-west and are vertical. Numerous breaks radiate from the Indian Creek plutons. The most recent faults and joints trend north-south. The early north-south faults dip east and are upthrown to the west. Some north-south faults are overthrust to the west with accompanying tears and shears.

The uplift of the crystalline core of the Front Range, on whose eastern flank the quadrangle lies, was accomplished by a multitude of step faults, each upthrown to the west. Later, thrusts from the east piled slices of granite and gneiss westward on each other.

Geologic and tectonic maps and cross sections, based on detailed mapping, on reconnaissance, and on a general inspection of previously mapped areas, are presented.

SYSTEM $NaAlSi_3O_8$-$KAlSi_3O_8$-H_2O

N. L. Bowen and O. F. Tuttle
Geophysical Laboratory, Washington, D. C.

In the presence of water vapor under pressure soda feldspar and potash feldspar crystallize readily from their glasses. At high temperatures they form a complete series of solid solutions showing continuous variation of optical properties and lattice spacing as measured by x-rays. Studies of the dry melts had indicated that the solid solutions are of the type having a minimum melting mixture. This

relation is established beyond question upon investigation in the presence of water. At a pressure of 1000 kg/cm² of water vapor the minimum lies at the composition 70 per cent $NaAlSi_3O_8$, and the temperature is 843°C. This temperature is 220° below that observed in dry melts, the lowering being induced by the presence of somewhat more than 7 per cent H_2O in the liquid phase or melt. Increase of pressure to 2000 kg/cm² produces a further lowering of only about one-third as much. When crystallized at still lower temperatures the complete solid-solution relation no longer obtains, and two feldspars form side by side.

ALTERNATING LAYER SEQUENCE OF RECTORITE

W. F. Bradley
Illinois State Geological Survey, Urbana, Ill.

Rectorite is a complex layer type hydrous alumino-silicate related to the better-known micalike minerals. The structural scheme of rectorite consists of contiguous pairs of pyrophyllite-like units separated by pairs of layers of water molecules. An equally apt description would be the alternation of one pyrophyllite unit with one vermiculite unit. The nature of the arrangement is confirmed by the preparation of the equivalent complex in which ethylene glycol proxies for water.

RELATION OF THE SEINE SERIES TO GRANITE AT EAST SHOAL LAKE, ONTARIO

E. L. Bruce and J. S. Ross
Dept. of Geology, Queen's University, Kingston, Ontario, Canada

The geological relations of the rocks of the Rainy Lake area west of Lake Superior have been a matter of controversy since they were mapped by Lawson in 1884–1887. At that time, Lawson included all the sediments in one series, which he named the Coutchiching. Later, on remapping the area, he concluded that part of the sediments belong to a later series, the Seine series, which he considered to rest on the eroded surface of an old granite and to be intruded by a younger one, the Algoman.

The last map of the area published by the Geological Survey of Canada shows only one granite, a granite intrusive into the rocks of the Seine series and all older rocks. There is no doubt of the presence of a post-Seine granite, but a study of pebbles from the Seine conglomerate at East Shoal lake shows them to be so strikingly similar to the granite near which they occur that it seems very likely that they have come from it and that therefore there were two periods of granite invasion, one before and one after the deposition of the Seine sediments.

DISTRIBUTION, OCCURRENCE, AND RESOURCES OF SUB-BITUMINOUS COAL AND LIGNITE IN THE WESTERN UNITED STATES*

Robert P. Bryson
U. S. Geological Survey, Washington, D. C.

In the western United States vast reserves of subbituminous coal and lignite, which have not been extensively developed to date because of their limited competitive position, are known to exist in several regions in beds, some thick and extensive and others thin and lenticular, associated with nonmarine sedimentary strata of Upper Cretaceous and lower Tertiary age. These reserves are located in California, Oregon, Washington, Idaho, Montana, North Dakota, South Dakota, Wyoming, Colorado, Utah, Arizona, New Mexico, and Texas.

West of the Rocky Mountain front the coal-bearing rocks dominantly are Upper Cretaceous. Where exposed, they commonly dip inward at the margins of structural basins, some of which may

* Published by permission of the Director, U. S. Geological Survey.

also have been separate basins of deposition at the time the coal was deposited. Individual coal beds commonly are lenticular in cross section and can be traced at most only a few miles along the outcrop. East of the Rocky Mountain front the coal-bearing rocks dominantly are lower Tertiary and are nearly flat or dip gently eastward away from the mountains. Especially in the Fort Union and Powder River regions some individual coal beds can be traced across hundreds of square miles.

Recent reserves estimates for some States, based on data obtained by systematic examination and mapping of western coal lands by the U. S. Geological Survey and by work of other organizations and individuals, agree in general though not in detail with earlier published estimates. More than nine-tenths of the subbituminous coal reserves of the United States are in Wyoming, Montana, and Colorado; and more than nine-tenths of the lignite reserves are in North Dakota and Montana.

RECENT RESULTS OF SUBOCEANIC GEOLOGY AND MAJOR EARTH PROBLEMS

Walter H. Bucher
Columbia University, New York, N. Y.

Rapid growth of knowledge always challenges current beliefs. The results here reported are no exception.

(1) Ewing's conclusions cast doubt on the belief that the floor of the Atlantic Ocean is underlain by a thin "granitic shell." Granitic material may be absent over large parts of all oceans.

(2) The great relief of the ocean floors and its patterns are incompatible with the continental drift hypothesis. The basalt floor cannot be considered the "matrix" through which the sialic "insets" moved differentially.

The structure of the Precambrian shields shows no evidence that an original granitic crust was "skimmed-off" the ocean basins to form continents. Every granite is intrusive into thick sediments and volcanics, deformed and metamorphosed like those of later orogenic belts. How, then, did the once-universal granitic crust of current belief disappear from the ocean basins?

(3) The island chain from Bonin to the Palau Islands, a typical "welt" and "furrow" belt, stands on the deep ocean floor as the Himalayan Mountain belt stands on the Continental level. It is high because it was raised. It does not differ essentially from the continental margins east and west. The question is clearly not "Why are the ocean floors low?", but "Why are the continents high?"

Perhaps the question is, similarly, not "Why is granite absent from the ocean floor?", but "Why is granite present in the continents?" Perhaps there is nothing "primordial" about granite; perhaps it is a byproduct of orogenesis. This is the same challenge to the old dogma of a primary granitic shell that has come from petrographers on very different grounds.

(4) The Mid-Atlantic Ridge and its lateral branches, which divide the Atlantic into basins, repeat on a larger scale the "swell" and "basin" structure of the continental surfaces. Its origin is unexplained. The presence of features associated on land with stream and shore erosion at great depths in the ocean present the sort of paradox which in the history of Science always pointed to a major gap in basic knowledge.

(5) The record of whatever agents have produced the geomorphology of the ocean floor must be sought in the character of the sediments, their rate of accumulation, thickness, distribution, and age. On the ocean bottoms as on land, stratigraphy and tectonics are needed for the comprehension of crustal dynamics.

GENERAL ASPECTS OF DISORDER IN MINERALS

M. J. Buerger
Massachusetts Institute of Technology, Cambridge, Mass.

The order-disorder relation is a particular and non-classical variety of polymorphism. Polymorphic transformations are governed by the Helmholtz free-energy relation, $A = E - TS$. It can be shown

that E, which appears as the latent heat of transformation, is always positive—*i.e.*, heat is absorbed with increasing temperature. In the classical polymorphic transformation, this occurs at a single temperature and coincides with the discontinuity of crystal structure at the transformation temperature. In disorder, there is no discontinuity, the heat being absorbed over a temperature interval culminating in the critical temperature of complete disorder. In this sequence, the basic crystal structure is not altered.

Disorder is ordinarily discussed for metals. Since metals have extremely simple crystal structures, only a simple and degenerate variety of disorder can occur in them. In more general crystal structures, disorder can occur in four distinct varieties: (1) Differential Interchange Disorder, (2) Interstitial Disorder, (3) Orientational Disorder, and (4) Distortional Disorder. Incidentally, distortional disorder is the mechanism of the high-low transformations in quartz, tridymite, and cristobalite.

The critical temperature of complete disorder falls with decreasing crystal size, and this accounts for the stabilization of high-temperature forms at room temperature. The disorder transformation is accompanied by symmetry changes, the lower temperature form having the lower (subgroup, or derivative) symmetry. This is responsible for transformation twinning.

SETTING OF ARIZONA IN CORDILLERAN STRUCTURE

B. S. Butler
University of Arizona, Tucson, Ariz.

The broader structures of the Cordilleran region of North America have been brought out on the geological maps of the United States and of North America, and especially on the Tectonic Map of the United States. Ransome, Lindgren, and others have pointed out that the region is divisible into structural belts that roughly parallel the western boundary of the continent. Schuchert has shown that the major basins of sedimentation had a similar trend.

Ransome subdivided the area into the Rocky Mountain belt, of complex structures, west of the Plains area. Next to the westward is the Plateau belt of comparatively simple structure, followed by the Nevada-Sonora belt of intermediate complexity and the coast belt of complex structure and strong igneous activity. Arizona occupies parts of the Plateau belt and parts of the Nevada-Sonora belt. The divisions of Ransome are not regular, and this is especially true in Arizona where the Colorado Plateau is essentially cut out to the south by the eastward extension of the Nevada-Sonora belt. The Colorado Plateau, as pointed out by Suess, is a relatively depressed area surrounded by a belt in which formations have been elevated thousands of feet higher than they are within the Plateau. The rocks in the surrounding belt are folded and thrust-faulted. In general the movement was toward the Plateau. It is suggested that the Plateau has been a relatively positive area surrounded by areas of relatively heavy sedimentation. The collapse of these basins with folding and thrust faulting has produced the elevated rim.

The Nevada-Sonora (basin and range) structure has been superimposed on parts of the Plateau structure.

MESOZOIC BOUNDARIES AND FAUNAL CHANGES

C. L. Camp
University of California, Berkeley, Calif.

Faunal succession may involve (1) extinction, (2) supplantation plus extinction or suppression of the earlier forms, (3) addition of new elements without extinction or suppression of older groups.

(1) Simple extinction must be due to many causes usually so complex as to be incomprehensible. It is certain that extinctions in one area are not always synchronous with those in another. (2) Extinction plus supplantation by newly developed groups with similar habits, habitats, and often with similar bodily forms, presumably occur more or less simultaneously (in respect to geologic time), and may therefore be more valuable in correlation and the fixing of time boundaries. (3) Addition of new

highly successful elements in a fauna may also be a rapidly spreading phenomenon, and consequently of value.

New elements usually appear in the record as migrants from an unknown geographic center. There is no way to determine whether or not they have arisen in an area of intense diastrophism. When they appear they may already be accompanied by new complementary elements (*i.e.*, herbivores plus highly developed carnivores); which makes it probable that we seldom see even the approximate time of original appearance of a group.

This leaves the possibility—indeed the probability—that many of the new faunas have arisen in the regions like many parts of the Southern Hemisphere, which were not affected by the diastolic changes of the North. When these changes came, certain forms already developed were ready to enter the new habitats and were not necessarily developed by the changed conditions.

FAVORABLE ORE ZONES OF THE NORTHPORT DISTRICT, NORTHEASTERN WASHINGTON*

Charles D. Campbell
The State College of Washington, Pullman, Wash.

The relative abundance of lead, zinc, and silver in dolomites of the Northport district, Washington, appears to depend on the stratigraphic position of the deposits within the Metaline limestone and the upper 900 feet of the underlying Maitlen phyllite, both of Cambrian age. The most favorable zone extends from 3400 to 4500 feet below the top of the 6000-foot-thick Metaline limestone. Twenty-nine per cent of the estimated lead production in the district, 89 per cent of the zinc, and 20 per cent of the silver came from this zone. Most of the deposits in this part of the section are sulfide replacements in fractures. In stratigraphic units outside the favorable zone the metals are less abundant, and the proportion of the three metals differs.

Correlation of ore type with stratigraphic position may be due to:

(1) development of more favorable structures for ore deposition in some zones than in others, dependent on the manner in which the rocks respond to stress;
(2) the varying proportions of the metals in different beds which may reflect original differences in chemical composition of the beds. There is no evidence of regular concentric zoning.

A series of maps, each showing the outcrop area of one ore horizon and the position of faults, shear zones, or other structural features that might localize ore in that horizon, would be a valuable guide to exploration and prospecting, but detailed mapping of the structure and stratigraphy of the entire potentially mineralized area is required before these maps can be drawn.

SUBMARINE GEOLOGY OF TWO NORTHEAST PACIFIC SEA MOUNTS

A. Carsola, R. S. Dietz, and R. D. Russell
U. S. Navy Electronics Laboratory, San Diego 52, Calif.

Erben and Noname banks, two flat-topped seamounts or "guyots" lying 800 and 600 miles west of San Diego, have been surveyed in some detail using recording echo fathometers. Sampes were obtained with dredges and snapper samplers, and bottom photographs were taken. These data indicate that both are basaltic cones which have been truncated by wave action. The truncated summits lie about 400 fathoms (Erben) and 280 fathoms (Noname) lower than present sea level.

NATURAL CLAY GROUT IN OPENWORK GRAVEL

Allen S. Cary
2815–28 Ave. W., Seattle, Wash.

A 100-foot bed consisting primarily of an original deposit of openwork gravel and boulders is exposed in a canyon of the Columbia River, Washington. A secondary deposit of clay was injected into

* Published by permission of the Director, U. S. Geological Survey.

the openwork gravel when about 4000 feet of ice overrode a clay bed resting on the gravel. The ice in turn deposited 200 feet of extremely compact glacial till over the gravel. Flow lines in the clay prove its injection into the voids of the gravel.

All the clay, both above and below ground-water level, exhibits shrinkage cracks. Evaporation explains the cracks above ground-water level. The hypothesis is advanced that the clay *below ground-level* became cracked by consolidation by molecular attraction of clay particles around irregularly spaced centers. Consolidation by molecular attraction within the clay will continue until the moisture film around the individual particles becomes so thin that its strength is equal to the molecular force tending to squeeze out the water.

OPTICS OF TRICLINIC ADULARIA

Ursula Chaisson
Dept. of Geology, University of Chicago, Chicago, Ill.

Adularia has been generally believed to be monoclinic. Sections of adularia from several localities studied on the universal stage show optical orientations inconsistent with monoclinic symmetry. Sections normal to [001] show approximately 8° inclined extinction; parallel to (001), 6°; parallel to (10̄1), 15°. The optical deviation from monoclinic symmetry is absent or very small in the core of the crystals but increases toward the surfaces. In the (110) and ($1\bar{1}0$) sectors, inclination of extinction from the (010) symmetry plane is clockwise; in ($1\bar{1}0$) and ($\bar{1}10$) it is counterclockwise. Adularia from St. Gotthard and Tavetschtal, Switzerland, Mt. Vesuvius, Italy, and Valencia, Mexico, conform to this pattern.

In monoclinic adularia, as has formerly been determined, $n\alpha$ lies in the symmetry plane and is very near the a axis. In triclinic adularia the plane containing $n\alpha$ and the c axis has rotated about the c axis and forms an angle φ with the original symmetry plante (010). The following values of φ were measured on adularia from given localities:

St. Gotthard	12°	different speciments
	10°	
Tavetschtal	9°	different specimens
	7°	
Valencia	10°	
Mt. Vesuvius	9°	

The deviation of φ is clockwise in sectors (110) and ($1\bar{1}0$); counterclockwise in ($\bar{1}10$ and ($1\bar{1}0$).

Heating of triclinic adularia to 1000°C. for 4 days changed the optical orientation toward monoclinic symmetry.

EUDIALYTE AND EUCOLITE FROM SOUTHERN NEW MEXICO

Stephen E. Clabaugh
2910 West Avenue, Austin, Texas

Eudialyte and eucolite occur in Otero County, New Mexico, in small irregular dikes associated with the Wind Mountain laccolith, a conical mass of nepheline-alacime syenite porphyry about 2 miles in diameter. The laccolith is the largest of a group of Tertiary alkalic intrusives that make up the Cornudas Peaks of Texas and New Mexico located at the eastern margin of the Sierra Diablo Plateau about 50 miles east of El Paso. The eudialyte-bearing dikes are peripheral apophyses which penetrate short distances into contact-metamorphosed limestones and shales of Permian and Pennsylvanian (?) age. Most of the eudialyte occurs in small subhedral to euhedral crystals about 0.5 to 3 mm. in diameter; it is distributed irregularly in the dikes and it is most abundant in narrow veinlike stringers that finger out into the calcareous rocks. The eudialyte ranges from rose pink and brown to colorless, and color is irregularly and zonally distributed in individual crystals. Eucolite occurs only

as cores of some of the zoned crystals. A sample of eudialyte from the west side of Wind Mountain has the following indices of refraction:

$$\omega = 1.588 \pm .002$$
$$\epsilon = 1.593 \pm .002$$

The indices of different zones of some crystals differ by more than .005, and parts of the zoned crystals are essentially isotropic. The identity of the eudialyte was checked by quantitative spectrographic analysis. Aegirite, alkali feldspars, nepheline, analcime, apophyllite, zeolites, and contact-metamorphic lime silicates are associated with the eudialyte.

Eudialyte has been reported from only two other localities in the United States—the Bearpaw Mountains, Montana, and Magnet Cove, Arkansas—, but it is not uncommon as an accessory mineral in nepheline syenite pegmatite and related rocks in many other parts of the world, notably in the Fennoscandian region.

GEOLOGIC RECONNAISSANCE IN CENTRAL ASIA

John Clark
Carnegie Museum, Pittsburgh, Penna.

Observations cover parts of northern Kashmir, the Chinese Pamirs, and the Taklamakan Desert, between 35° and 39°30′ N., and 72° and 76°30′ E.

From south to north the area consists of:

(1) The Himalaya Range, basic plutonics;
(2) a series of gneisses, intruded by (1) and (3);
(3) the Kailas Range, basic plutonics;
(4) a thick series of schists, marble, and quartzite, intruded by (3) and (5);
(5) the Great Karakorum Range, acid plutonics;
(6) an upper Paleozoic series of sediments, extensively faulted, not intruded;
(7) the Kuenlun Range, intermediate plutonics;
(8) the Chinese Pamirs, faulted and folded sediments.

Extreme relief is 22,000 feet in 15 miles, at Nanga Parbat; average relief is 12,000 to 15,000 feet. The average surface slope of the entire area south of the Kuenlun is above 35°. The climate is temperate and Arctic desert. Erosion and transportation by running water are significant only in the actual beds of the permanent streams. Most erosion is accomplished by landslides, initiated by wind and earthquakes, and by avalanches and glaciers. There is evidence of several temporary halts in downward erosion. Glaciers have receded less than 5 miles, but they are apparently receding actively at present.

The Pamirs were never extensively glaciated. They are covered with fine, tan, powdery silt, which is water-laid at elevations above 12,000 feet and is being transported to the Taklamakan by both water and wind.

PALEOECOLOGICAL STUDY OF THE PENNSYLVANIAN EXLINE LIMESTONE OF IOWA AND MISSOURI

L. M. Cline and B. H. Burma
University of Wisconsin, Madison, Wis.; University of Nebraska, Lincoln, Nebr.

A paleoecological study has been made of the Pennsylvanian Exline limestone of Iowa and Missouri. The Exline, which is only about 1 foot thick but very persistent, was sampled from central Iowa to west-central Missouri, an outcrop distance of 270 miles. Preliminary field work had indicated lateral gradation from a light-colored calcitic limestone to a dark-gray calcareous shale with correlative faunal variations. Chemical analyses supplementing and extending the field observations have

permitted recognition of six chemical facies. Lines contouring equal percentages of CaO, MgO, Fe_2O_3, P_2O_5, and total insolubles show a marked parallelism. An eastward increase in CaO and a westward increase in the other constituents suggest that the Nemaha uplift strongly influenced sedimentation as late as Exline time.

The Exline fauna is surprisingly large, comprising approximately 90 species of marine invertebrates. There is a good correlation between faunal and chemical composition, the correlation being particularly strong for the mollusks. Facies A, a relatively pure calcitic limestone, is characterized by a mixed brachiopod, bryozoan, and crinoid fauna. Facies B, C, and D, moderately argillaceous limestones, are dominated by brachiopods. Facies E, an argillaceous nonmagnesian limestone, is dominated by the mollusks, which phylum is largely restricted to this facies. Facies F, a calcareous magnesian shale, is characterized by the brachiopod *Crurithyris* and by tetracorals.

PETROLOGY OF THE RED RADIOACTIVE ZONES NORTH OF GOLDFIELDS, SASKATCHEWAN

Charles E. B. Conybeare and Charles D. Campbell
The State College of Washington, Pullman, Wash.

The red rocks that occur along faults and shear zones in the Precambrian granitic terrane north of Lake Athabaska are more radioactive than others in the area. They are mylonites ranging from protomylonite to ultramylonite, the latter generally forming anastomosing veinlets in the less intensely crushed types.

In the protomylonites the feldspar is deformed albite colored with hematite dust, especially along the cleavages; unstrained minerals fill the interstices. In the more intensely crushed types the hematite dust permeates most of the rock; the unstrained minerals present form scattered aggregates or may locally replace the mylonite completely.

The first of these late minerals is clear albite, which rims the red albite relics. Then follow, in variable order and with repetitions, clear subhedral quartz and albite, specularite, and penninite containing radioactive anatase grains. The latest veins contain also pitchblende, calcite, and specularite. Oxidation products of pitchblende are locally abundant in solution cavities.

The early iron and later radioactive elements were introduced probably by solutions that rose along the mylonite zones. The other elements were probably present before mylonization; and all the late minerals, excepting pitchblende and calcite, may be products of recrystallization.

There is no evidence that the dusty hematite is an exsolution product of iron-rich feldspar.

SEDIMENTARY CYCLES IN THE DUNKARD AND MONONGAHELA SERIES OF OHIO*

Aureal T. Cross
West Virginia Geological Survey, Morgantown, W. Va.

The Dunkard and Monongahela series of Ohio include about 40 depositional cycles, grouped into a smaller number of units (macrocyclothems) based on widespread general similarities of several successive single cyclothems (microcyclothems). Microcyclothems are generally incomplete in most localities, but a composite section shows a rather standard sequence of lithologic units which varies more in distance from the Ohio River westward than from preceding and succeeding microcyclothems.

The normal sequences are (in ascending order): (1) Monongahela series—sandstone, calcareous siltstone, thin-bedded fresh-water (?) limestone, clay-shale, coal, dark limestone (brackish-water fauna), shale (clayey) with roof coals (plant fossils), shale (silty, calcareous), unconformity or sandy shale. (2) Uppermost Monongahela and the Washington and Lower Greene of Dunkard—sandstone, silty limestone (nonfossiliferous), argillaceous limestone (green and purple, nonfossiliferous), argil-

* This work represents a portion of that done earlier while the author was Geologist, Geological Survey of Ohio, and is presented with the permission of the State Geologist, Geological Survey of Ohio.

laceous limestone (gray-green, nodular, microfossils), clay-shale (thin), coal, dark limestone (brackish-water fauna), coal (bony and shaly), shale (clayey, plant fossils), shale (silty, calcareous, with roof coals), unconformity or silty, calcareous shale. (3) Upper Greene—sandstone, silty limestone, argillaceous limestone (green and purple), argillaceous limestone (gray-green with lime nodules) or thin-bedded limestone (with fossiliferous dark shale and coal partings, bone beds, etc.), clay-shale (streak), coal (often absent), shale (plant fossils), and unconformity or sandy shale.

The sandstones are extremely variable and unreliable for mapping. The clay-shales are thin, persistent, nonstigmarian, and have a plastic clay zone at top. The coals usually are multiple-bedded and have an associated dark, fossiliferous limestone. The argillaceous limestones are soft, shaly, conspicuous when weathered, and, in the Monongahela series, replace the thin-bedded limestones laterally, westward. Occasional bone beds and marine invertebrates are found.

"TURTLEBACKS" OF CENTRAL BLACK MOUNTAINS, DEATH VALLEY, CALIFORNIA

H. Donald Curry
Shell Oil Company, Casper, Wyo.

The name "turtlebacks" was first applied by L. F. Noble (1941) to several surface features that lie on the west slope of the Black Mountains where they face the lowest part of Death Valley, Inyo County, California. On the basis of study and mapping of an area about 8 by 20 miles from 1933 to 1939 and revised in 1949 by the use of new air photographs, three "turtlebacks"—Badwater, Copper Basin, and Mormon Point—are interpreted as folded fault surfaces cut across a basement of Archean crystalline rocks. The surfaces are overlain by remnants of a plate made up of late Tertiary sediments and flows, blocks of lower Paleozoic rocks, and some crystalline rocks in great confusion.

The surfaces of the three "turtlebacks" are uncommonly smooth as they have only been etched by minor ravines and canõns. Each has an areal extent of many square miles and a relief of several thousand feet. The foliation of the underlying metamorphic rocks is broadly parallel to the axes of the "turtlebacks".

Since the remnants and bordering belt of the overlying Tertiary layered rocks are discordant with the underlying crystalline rocks, they are regarded as part of a composite sheet that was first thrust upon a flat crystalline basement and later folded into the three anticlines that form the "turtlebacks". Noble in 1941 applied the term "chaos" to remnants of a similar plate in the Virgin Spring area.

In both areas, mid-Tertiary sediments and flows are involved so the thrust must have formed in later Tertiary time.

SEA-FLOOR INVESTIGATIONS IN THE NORTH PACIFIC AND BERING SEA

R. S. Dietz and E. C. Buffington
U. S. Navy Electronics Laboratory, San Diego 52, Calif.

Some preliminary results of an investigation of the sea floor in the North Pacific and in the Bering Sea are discussed. These findings, collected in connection with a U. S. Navy cruise during the summer, 1949, are compared with previous information collected during the summer of 1947.

TIDAL-FLAT ENVIRONMENT

D. J. Doeglas, A. Koning, and J. H. Germeraad
School of Geology, L.S.U., Baton Rouge, La.

Recent sediments from borings and present-day surface deposits of the Tidal Flats in the northern part of the Netherlands have been studied paleontologically and petrologically. The salt content of the water has been determined. The fauna belongs to the upper neritic zone as found by S. W. Low-

man in the Gulf of Mexico. Estuarian deposits at the landward side of the flats have a foul-water fauna. The size-frequency distribution is very constant and characteristic. The median size of the sands is 160 microns. The shape of the size-frequency curves of the sands and argillaceous deposits is characteristic of tidal-flat environment. The clay-mineral assemblage of the argillaceous deposits and the suspension of the sea water consists mainly of illite with minor amounts of kaolinite and montmorillonite. The contents of iron and carbon vary with that of the grades smaller than 16 microns.

NOTES ON THE IRON ORES OF CENTRAL MINAS GERAIS, BRAZIL*

John Van N. Dorr, II and Philip W. Guild
U. S. Geological Survey, Washington, D. C.

Preliminary results of a continuing co-operative research project of the United States Geological Survey and the Brazilian Departamento Nacional da Produção Mineral on the geology and hematite ores of Central Minas Gerais are summarized.

For economic purposes the ores can be divided into three types:

(a) hard lump ore averaging about 68 per cent Fe.

(b) fine to powdery ore averaging approximately 68 per cent Fe.

(c) soft, easily concentrated quartzose protore averaging perhaps 50 per cent Fe.

Although type (a) is the only one now being exported, the other types will have to be mined to produce lump ore on a large scale. Therefore either exportation of run-of-mine ore, or concentration or reduction in Brazil of the finer ores, seems logical. The sale abroad of concentrates or pig iron would pay for the importation of needed fuel.

Field work suggests that the Brazilian iron formation, itabirite, is a metasediment derived from banded iron oxide—jasper rock similar to much of the iron formation of the Lake Superior region. Many bodies of pure hematite are demonstrably the result of replacement of silica in the protore by hematite; that all the large bodies have this origin cannot be proved, though it seems probable. Regional metamorphism and the relative mobilities of silica and hematite under stress seem to have played a major role in this replacement, for many bodies occur at or near points of intense deformation. Hypogene solutions may also have been active.

The source of the iron and silica may be related to volcanic activity, as indicated by the enclosing rocks, thought to be in part metavolcanics.

The pure ores are to be measured in hundreds of millions of tons, and the easily concentrated protores in billions of tons.

GLACIATION OF THE COEUR D'ALENE MINING DISTRICT, IDAHO

Wakefield Dort, Jr.
Dept. of Geology, Duke University, Durham, N. C.

During the last glaciation a minimum altitude of 5300 feet was necessary for the formation of minor ice masses in favorable locations on north-facing slopes. Snow collecting in higher valley heads nourished ice streams which flowed to elevations as low as 3900 feet, cutting large cirques and U-shaped valleys. The longest ice stream, in the valley of Canyon Creek, extended for approximately 5 miles. It flowed westward almost to the town of Burke and impounded ponds in the lower tributary gulches. No ice masses formed on south-facing slopes.

Well-preserved striations with subparallel orientation occur on several major ridge crests and could not have been formed by restricted valley glaciers. Large angular to subangular boulders of granitic rock are scattered along the major drainage line of the South Fork of the Coeur d'Alene River several hundred feet above the present stream. One very large boulder near the town of Kellogg,

* Published with the permission of the Director, U. S. Geological Survey.

well striated and grooved, indicates the presence of ice more than 15 miles beyond the terminus of the Canyon Creek glacier. These granitic boulders may have come westward from the Gem Stock near Burke, or from the Idaho batholith to the south. A boulder of vesicular basalt appears to have been brought from the Columbia lava fields to the south or southwest. A much greater extent of the ice is indicated than that evidenced by cirques and U-valleys now existing.

High-terrace gravels, as much as 900 feet above present drainage, but containing striated pebbles and cobbles, indicate a period of canyon cutting between stages of ice formation. The earlier advance may correspond to the Spokane advance of Bretz. The later was Wisconsin.

WALL-ROCK REPLACEMENT BY OXIDIZED COPPER MINERALS

R. M. Dreyer, A. L. Howland, R. M. Garrels
Univ. of Kansas, Lawrence, Kans.; Northwestern University, Evanston, Ill.; Northwestern University, Evanston, Ill.

Initial deposition of copper carbonates and copper silicates as crustifications or replacements in carbonate wall rocks occurs, in many places, as clusters of radiating needles. Complete replacement may be effected by the coalescence of such clusters. Crustification over spherical clusters may produce a botryoidal surface. A replacement layer may contain several alternating colloform bands of copper carbonates and copper silicates. A variation has been noted in the composition of chrysocolla.

PACIFIC COAST TERTIARY MARINE CLIMATES

J. Wyatt Durham
Department of Paleontology, University of California, Berkeley, Calif.

Based on the premises that past requirements of associations of organisms are similar to present-day needs, and that, within the limits of temperatures normally prevailing in marine waters, stenothermal organisms are much more critically limited by minimum temperatures than by maximum temperatures, an interpretation of marine climates prevailing during the Tertiary is presented. The close relationship of early Tertiary faunas of the Pacific Coast and Kamchatka, together with the distribution of tropical faunas around the Pacific basin at the same time, indicates that the poles and the continents could not have been in the positions postulated by Wegner.

The data available indicate that in the Upper Cretaceous the February 20° C. marine isotherm along the Pacific Coast must have been some place between 50° and 55° N. Lat. and that it gradually migrated southward, possibly with minor fluctuations, during the Tertiary until the Pleistocene. During the Pleistocene it obviously fluctuated both northward and southward, but the correlations available during that interval do not permit of a synthesis of the data. During the Paleocene and Eocene the 20°C. isotherm was north of 49° N. Lat.; during the middle Oligocene it was near 48° N. Lat.; in the middle Miocene it was at about 35° N. Lat.; during the middle Pliocene it was around 28° N. Lat.; possibly during the upper Pliocene it was near 30° N. Lat. At present the 20° C. isotherm is near 24° N. Lat. in February.

ENGINEERING GEOLOGY BRANCH, U. S. GEOLOGICAL SURVEY*

Edwin B. Eckel
U. S. Geological Survey, Box 2858, Lakewood Branch, Denver, Colo.

An Engineering Geology Branch was first organized by the U. S. Geological Survey in mid-1945. During the ensuing 4 years, many mistakes and considerable progress have been made. One of the most difficult problems to solve has been a definition of the field of engineering geology within a

* Published by permission of the Director, U. S. Geological Survey.

scientific organization not involved in engineering construction. With few exceptions, this Branch does not perform geologic examinations of specific construction sites—a job that is better handled by private consultants or by geologists attached to the construction agencies' staffs. Instead, the Federal Survey's job is believed to lie in providing broad-scale maps and other geologic information that can be used directly as background data by either the site geologist or the designing engineer. Emphasis is on production of mile-to-the-inch maps of areas where heavy construction of any kind is anticipated. The maps themselves are like other orthodox geologic maps. Every effort is made, however, to describe the rocks and structures in terms of physical properties that have a bearing on engineering planning, design, or construction. In some cases, a single map suffices to show all the necessary facts; in others, special interpretive maps or other illustrations are used. A second phase of the Branch's work consists of basic research aimed at defining geologic phenomena in terms most useful to engineers. Examples of both research and mapping projects now under way are presented.

SUBSURFACE WOODFORD BLACK SHALE OF WEST TEXAS AND SOUTHEAST NEW MEXICO

Samuel P. Ellison, Jr.
Dept. of Geology, University of Texas, Austin, Texas

Maps showing the thickness and subsurface distribution of the Woodford black shale are presented. A detailed analysis of the lithologic units of the Woodford is included, and correlations of these units are aided by evidence from electric and radioactive logs. Inferences are made concerning the environment of sedimentation. The Woodford is considered upper Devonian in age on the basis of brachiopods, conodonts, and plant remains.

SEISMIC STUDIES IN OCEAN BASINS

Maurice Ewing
Columbia University, New York, N. Y.

Seismic refraction measurements have been made at over a dozen stations in the North Atlantic Ocean. Of these, 4 are reversed and of excellent quality, 6 are either unreversed or of lower quality, and the remainder are fragmentary. In general these measurements show that the basement rocks have a velocity of about 7.6 km/sec, and we have tentatively identified them with the rocks through which the P_n earthquake waves are propagated at depths of about 40 km under the continents. The refraction measurements indicate that these rocks are covered with approximately 2 km of unconsolidated sediments.

Seismic reflection measurements, using instrumentation and techniques which are rather primitive by the standards which prevail in oil prospecting, have been made at over 3000 stations in the North Atlantic Ocean. Over large areas it is not yet possible to interpret these measurements in terms of reflecting surfaces which are continuous over distances of tens of miles, for example, on the approaches to continents, in the main basins, and on the central highland of the Mid-Atlantic Ridge. Over other large areas, namely the eastern and western flanks of the Mid-Atlantic Ridge and throughout the Bermuda Rise, it is possible to map a buried reflecting surface which is continuous over hundreds of miles at depths up to 4000 feet below the ocean floor. The sediment above this reflector is in general remarkable for its homogeneity as indicated by the absence of intervening reflectors. This reflecting surface—in the areas last mentioned—is very probably the surface of the basement rocks.

A new theory for the dispersion of earthquake surface waves under the oceans has been proposed, which can be interpreted to indicate that our seismic refraction results are valid for most, if not all, of the Atlantic and the Pacific Ocean basins. If this conclusion becomes generally accepted, either by ocean-wide coverage by seismic refraction stations or by agreement with our interpretation of the surface waves, it will constitute strong evidence that the ocean basins have never stood appreciably higher with respect to the continents than they do at present.

If there have been land bridges across the main ocean basins, we believe they must have been very narrow, covering only a small percentage of the total area of the ocean basin, and that they do not cross any of the areas where we have made refraction measurements. We consider that the refraction measurement would give unmistakable evidence of any such former land bridge.

SYNTHETIC QUARTZITE

H. W. Fairbairn
Massachusetts Institute of Technology Cambridge, Mass.

Quartz sand (grain size 125–250 microns) immersed in weak aqueous Na_2CO_3 solution is converted to sheared quartzite (grain size 100–200 microns) after a few hours' exposure to temperatures in the range 225°–450°C, confining pressures between 5000 and 30,000 psi, and compressive loads between 35,000 and 115,000 psi. The principal feature of the experimental procedure is the use of a piston of rectangular cross section and of a sand receptacle designed so that a biaxial strain is imposed on the quartz aggregate. The deformed prisms show shortening up to 60 per cent, elongation up to 20 per cent, and net decrease of volume up to 52 per cent. Individual quartz grains have a maximum elongation of 2:1. Undulatory-extinction bands are abundant, but no trace of deformation lamellae was found. There is little evidence of recrystallization. Both compaction and dimensional orientation are best developed in the upper range of temperatures and pressures used. Investigation of the lattice orientation (axis diagrams) of 35 deformed prisms shows random orientation for the most part. Calculation of the coefficient of correlation for each scatter diagram has also been carried out to test statistically this apparent randomness, but with inconclusive results.

Several similar experiments, using H_2O instead of Na_2CO_3, show a much lower degree of compaction and no trace of dimensional orientation—even, for example, after 6 days' exposure to 350°C., 30,000 psi confining pressure, and 77,000 psi compressive load.

NEW FOSSIL FOOTPRINTS FROM COLORADO*

H. Faul and W. A. Roberts
U. S. Geological Survey, Washington, D. C.

The first collection of a new ichnite fauna from sandstone of probable Lower Jurassic age is described. The numerous tracks and markings were made by reptilian and other vertebrates (both quadrupedal and bipedal), arachnids, a gastropod, and scolithoid and other types of "worms". The rock is a pure, fine-grained, cross-bedded aeolian sandstone with the foresets dipping predominantly south. The material was collected atop Flag Ridge, about 10 miles south of Meeker, Colorado. Farther south the same formation contains the extensive vanadium ore body at Rifle.

NEUTRON LOGGING OF DRILL HOLES

Henry Faul, C. W. Tittle, and Clark Goodman
U. S. Geological Survey, Washington, D. C.; North Texas State College, Denton, Texas; Massachusetts Institute of Technology, Cambridge, Mass.

Distribution of thermal and indium resonance neutrons and intensity of secondary gamma radiation have been measured in continuous media and in simulated drill holes, cased and uncased, empty and water-filled. Water, barite-drilling mud, brine, water-saturated sand, moist sand, and brine-saturated sand were investigated. Neutron distributions in water and drilling mud (density 1.4) are nearly identical.

* Published by permission of the Director, U. S. Geological Survey.

The intensity of neutron-capture gamma rays depends on the hydrogen content of the rock. In a 6-inch well, it increases with hydrogen content at points within 16 inches of the neutron source and decreases at more distant points. The absolute gamma intensity is greatly reduced when nonhydrogenous absorbers (for example: lead and boron) are introduced between logging probe and formation. The slope of logarithmic intensity vs. distance remains virtually constant. It changes with the hydrogen content of the formation and offers a means of quantitatively estimating porosity behind casing despite extraneous absorption. Hydrogenous material between probe and rock increases the slope. Two or three inches of mud seriously impairs the sensitivity.

The ratio R of space integrals of thermal and indium resonance intensities in the well is a monotonic decreasing function of the macroscopic thermal neutron capture cross section of the formation (chlorine is the major contributor: $\sigma = 33$ barns, compared to 2 barns or less for most other common elements). R_{water}/R_{brine} is 1.2 for 2 per cent brine in a cased 4-inch well, and increases to 2.2 for saturated brine. The field application of these techniques remains to be evaluated.

STRUCTURAL RECONNAISSANCE OF THE RED ROCK QUADRANGLE, ARIZONA*

John H. Feth
U. S. Geological Survey, Box 2270, Tucson, Ariz.

Geologic structures of the Red Rock quadrangle, south-central Arizona, and their relation to the occurrence of ground water are discussed.

Lithologic units involved range in age from metamorphic rocks of possible Precambrian age to Quaternary alluvium. The most prominent units consist of volcanic flows and clastic rocks of probable Cretaceous and Tertiary age.

A northwest structural pattern, prominent in southeastern Arizona, is recognized in the Red Rock quadrangle. High-angle normal faults, possibly accompanied by gentle anticlinal arching or by overthrusting, are believed to govern the outlines of the principal valleys. Where measured, the faults dip toward valley axes at angles up to 85°.

Picacho Peak, a prominent landmark, is interpreted on petrographic evidence as a plug of Quaternary basalt piercing volcanic rocks of probable Cretaceous and Tertiary age.

Occurrence of pediment areas carved on Precambrian (?) metamorphic rocks and Precambrian (?) granite is discussed in relation to occurrence of ground water. Supplies of ground water in quantities large enough to permit irrigation are believed to be present only in the valley of the Santa Cruz River, where Quaternary alluvium is the chief aquifer.

MICROSTRUCTURE OF SOME PENNSYLVANIAN NAUTILOIDS

Alfred G. Fischer and Robert Finley, Jr.
Dept. of Geology, University of Kansas, Lawrence, Kans.

The cephalopod fauna of the Buckhorn asphalt, a littoral sediment of Oklan age in the Arbuckle Mountains of Oklahoma, is exceptional among Paleozoic faunas in the preservation of the nacreous luster and microstructure of aragonitic shell material. The Buckhorn sediment was laid down as a shell breccia in argillaceous and sandy matrix, grading upward into gravel. Shortly after this, the faulting of the Arbuckle orogeny permitted Ordovician oil to saturate the sediment. In the resulting asphalt the shells were protected from circulating ground waters and were altered little or not at all. This has made it possible, for the first time among Paleozoic nautiloids, to determine the microstructure of shell wall, septa, protoconch, and cameral deposits. The latter are doubtless of organic origin, the product of cameral mantle tissues, and are taxonomically of great potential importance. Wall structure promises to be an important aid in the separation of the major groups of cephalopods.

* Published by permission of the Director, U. S. Geological Survey.

CONE-AXIS DIFFRACTION PATTERNS

D. Jerome Fisher
Dept. of Geology, University of Chicago, Chicago, Ill.

Cone-axis X-ray pictures have been briefly described by Buerger (ASXRED Monogr. 1, 1944). They are obtained when a lattice translation direction is given a precessing motion with respect to the direct beam, providing a flat film is placed in the holder normally occupied by the layer-line screen. The result is a series of diffracted spots which lie along concentric circles ("rings"), one for each level of the reciprocal lattice within range. A cone-axis photo bears about the same relation to a precession picture that a rotation film has to a Weissenberg.

While cone-axis photos are useful in determining the value of d^* in the precessing direction, they may also be employed to get diffraction symmetry and to check orientation; such uses will be illustrated. It is possible to index the spots of a cone-axis ring by a simple graphical procedure. This consists of making a trace-o-film enlargement of the spots to the proper scale to fit a precession photo of the same level. The trace-o-film is held in a framework on the arm of a universal drafting machine, and its center is moved above a suitable guide circle drawn on the n-level precession photo. This recapitulates the actual motions of the precession instrument. Thus, when a spot on the trace-o-film lies above a spot on the precession photo, the two have the same index, easily obtained from the precession photo. This technique wll also be illiustrated with simple cases that do not involve too many spots.

USE OF A VARIABLE-FIELD ELECTROMAGNETIC MINERAL SEPARATOR IN SEDIMENTARY PETROGRAPHY

J. D. Frautschy
Scripps Institution of Oceanography, La Jolla, Calif.

Any detrital mineral grain is magnetic, the kind and degree being a function of composition. A variable-field electromagnetic mineral separator has been devised to separate aggregates of grains into diamagnetic, paramagnetic, and ferromagnetic classes. The paramagnetic and ferromagnetic separates may be subdivided on the basis of the magnetic susceptibilities of the individual grains.

Separation is accomplished by pouring a test sample as small as 0.1 gram down an inclined vibrating trough which passes over a ring-shaped magnetic field. The magnetic gradient of the field can be adjusted to any value within a wide range. Grains retained by a given field remain on the trough, and grains of lower susceptibility pass down the trough into a small container. By repeating the process with progressively higher field gradients, separates of progressively lower susceptibilities can be collected and weighed. The distribution of magnetic susceptibilities can then be plotted, and the statistical methods of size-distribution studies can be used to describe the curve. Information of this type may supplement optical studies in some problems. Other applications of the separator include aid in identification of opaque grains, elimination of a very abundant mineral from a sample to be studied optically, and collection of single mineral concentrates.

CYPHASPIS AND OTHER TRILOBITES FROM OKLAHOMA

E. A. Frederickson
University of Oklahoma, Norman, Okla.

The occurrence of *Cyphaspis* and *Remopleurides* from the Bromide formation of the Simpson Group, and *Odontopleura* from the Haragan formation of the Hunton group is reported. The presence of these forms in the respective formations is of special interest because it greatly extends the geographic range area of these genera.

LIQUID IMMISCIBILITY IN THE Na_2O-SiO_2-H_2O SYSTEM.—PRELIMINARY DATA ON THE Na_2O-SiO_2-AL_2O_3-H_2O SYSTEM

I. Friedman
Dept. of Geology, University of Chicago, Chicago, Ill.

The system Na_2O-SiO_2-H_2O was investigated at 400° and 450°C. The water-rich immiscible phase present at 250°, 300°, and 350°C has a critical endpoint at about 400°C.

Some of the stability relationships of albite and analcite in the system Na_2O-SiO_2-Al_2O_3-H_2O will be discussed.

SURVEY OF THE MINERALOGY OF URANIUM

Clifford Frondel
Harvard University, Cambridge, Mass.

The descriptive mineralogy of uranium is discussed with regard to (1) the status of existing descriptions of the known uranium minerals, (2) the directions of needed investigation, and (3) the methods of identification and study. Particular reference will be made to the crystal structure of uranium minerals of the formula-type $A(UO_2)_2(XO_4)_2 \cdot nH_2O$ and to the correlation of optical, physical, and chemical properties therewith.

DISORDER IN SULPHIDES

Alfred J. Frueh, Jr.
Dept. of Geology, University of Chicago, Chicago, Ill.

Heretofore metallurgists and physicists have made the most significant advances in the study of disorder, using for their examples intermetallic compounds. To use this knowledge to the fullest in initiating studies of disorder in minerals, sulphides were chosen, because of their submetallic character and because of the similarity between the covalent bonds in the sulphides and the metallic bond in the intermetallic compounds.

Bornite (Cu_5FeS_4), chalcopyrite ($CuFeS_2$), and stannite (Cu_2FeSnS_4) were chosen for laboratory study because they are often the hosts in exsolution textures. The presence of such textures indicates that solid diffusion exists in the mineral at elevated temperatures. As all these minerals have two different atoms of similar size and properties (copper and iron), the chances of self-diffusion of these atoms in the structure and subsequent disorder when heat-treated would seem to be great.

X-ray, thermal, and electrical evidences indicate that bornite can exist in both a low- and high-temperature form, and that the structural difference between the forms is one of order-disorder. When thermally induced, the disorder first reaches a measurable magnitude at 170°C., and the critical temperature of complete disorder is reached at 220°C. By quenching in cold water, the high or disordered form can be retained, but if cooled slowly from the elevated temperature the low form is regained.

X-ray evidence indicates that both stannite and chalcopyrite can exist in a disordered form above a temperature of 600°C. However, as dissociation of these sulphides occurs below this temperature at atmospheric pressure, experimental technique has not yet been worked out to determine the thermal and electrical characteristics of the change.

THRUST FAULTING IN THE EMPIRE MOUNTAINS, SOUTHEASTERN ARIZONA

Frederic W. Galbraith
4325 E. Whitman, Tucson, Ariz.

The Empire Mountains are approximately 30 miles southeast of Tucson. The bulk of the range is limestones, shales, and quartzites of Cambrian, Devonian, Mississippian, Pennsylvanian, and Per-

mian age, overlain by 15,000 feet or more of Cretaceous continental clastics. Stocklike bodies of quartz monzonite and granodiorite and dikes ranging from rhyolite to basalt intrude the sedimentary rocks.

The range consists of a basement block of younger Cretaceous and an overthrust block of Paleozoic and older Cretaceous. The fault plane outcrops along the western edge of the range.

The basement block exhibits a series of broad folds with east-west axes; rocks in the overthrust block have a prevailingly eastward dip. The overthrust block is broken by northwesterly striking tear faults, dividing it into three sections. Imbricate structure is striking in the northern section; at least three thrust sheets are present.

Part of the western margin of the range is delineated by a gravity fault, along which the stratigraphic displacement is some 15,000 feet. It is interpreted as due to small-scale normal faulting of the toe of the overthrust block.

The northern section of the overthrust block is domed; the central section is folded into an asymmetrical anticline; and the southern section has been rotated on the thrust plane so that prevailing dips are south or southeast.

PRECIPITATION OF BASIC COPPER

R. M. Garrels, A. L. Howland, and R. M. Dreyer
Northwestern University, Evanston, Ill.: Northwestern University, Evanston, Ill., University of Kansas, Lawrence, Kans.

The precipitation of pH of basic copper chloride (atacamite) and basic copper sulfate (brochantite) was determined at 25°C. and 45°C. over a wide range of concentration of the original copper chloride and copper sulfate solutions. Precipitation was induced by addition of sodium hydroxide. The same compounds precipitated at the surface of calcite or dolomite rhombs immersed in copper chloride or copper sulfate solutions. The mechanism indicated is a local neutralization of acidity at the mineral surface as hydrogen ions from solution react with carbonate ions of the solid, permitting the formation of the basic copper mineral in this neutralized zone. All experimental work indicates that basic copper carbonate such as malachite or azurite does not form by direct reaction of concentrated copper-bearing solutions with carbonate rocks. Only at concentrations of copper sulfate or copper chloride of approximately 10^{-4} M. or less did malachite form by direct reaction. The precipitated atacamite and brochantite are very fine grained, with a tendency to "weld" and form an impervious coating on the calcite or dolomite. However, aging of the original precipitate seems to occur, eventually causing increase in grain size and in porosity of the precipitated layer. Iron in the solution prevents immediate reaction of copper with limestone; the copper tends to "travel" when the solution is forced through limestone.

PETROLOGY OF BAUXITE SURROUNDING A BOULDERLIKE CORE OF KAOLINIZED NEPHELINE SYENITE IN ARKANSAS* (EXHIBIT)

Marcus I. Goldman
707 20 St. N.W., Washington, D. C.

Alteration of feldspars to finely crystalline gibbsite, of this gibbsite to more amorphous-looking concretionary bauxite, and subsequent kaolinization of these alteration products by silica derived from the unbauxitized core is described and illustrated. There is an envelope of hard limonite in the outer part of the kaolinized bauxite. The probable beginnings of kaolinization are seen in a specimen, from the center of the core, in which there are remnants of feldspars. Distortion, resembling flowage near the inner gibbsitic edge of the bauxite envelope where kaolin is abundant, is attributed to expansion resulting from kaolinization. Dark-brown ferruginous carbonates are present in all bauxite-free kaolin specimens, even in kaolin believed to be derived from silication of bauxite, but there are none where bauxite is present. Sphene altered to leucoxene is present throughout but is increasingly

* Published by permission of the Director, U. S. Geological Survey.

corroded and scarce in the more peripheral, more mature bauxite. Sulfides were found only in the kaolinized center of the core. Reduction of crystalline gibbsite to amorphous-looking cliachite may be the first step in the dehydration of part of the gibbsite to one of the monohydrates, diaspore or boehmite. As an envelope of bauxite could not form around a weathering core if the bauxite recombined to form kaolin with silica escaping from the core, probably when bauxitization was the prevailing weathering process kaolin was not forming, at the same time, as an intermediate product.

SIGNIFICANCE OF GALLIUM AND GERMANIUM REPLACEMENTS IN SYNTHETIC FELDSPARS

Julian R. Goldsmith
Dept. of Geology, University of Chicago, Chicago, Ill.

It is difficult to locate specific positions of Al and Si atoms in many silicates because of the approximately equivalent X-ray scattering power of these two atoms. In studying order-disorder relations in silicates, particularly in feldspars, location of these positions is desirable. The synthesis of feldspar structures in which Al^{+++} is replaced by Ga^{+++}, and Si^{++++} by Ge^{++++}, and some of their crystal-chemical properties are discussed; the heavier elements make it possible to obtain more definite information on the degree of disorder. It is hoped that these gallium and germanium feldspars will help in the interpretation of some of the problems of the natural feldspars.

RHEOMORPHIC BRECCIAS

G. E. Goodspeed
Dept. of Geology, University of Washington, Seattle, Wash.

Igneous intrusive breccias display the well-known features resulting from the injection, crystallization, and reaction of an orthomagma. In contrast many breccias in granitized areas contain undisturbed rock fragments and skialiths surrounded by granitic matrices which exhibit crystalloblastic textures and structures. These are considered to represent an intermediate stage of granitization and have been called replacement breccias.

Other plutonic breccias associated with granitization have crystalloblastic features similar to replacement breccias but exhibit fluxion textures. At Cornucopia, Oregon, the matrices of some of these breccias show flow structures. At Sudbury, Ontario, some of the breccia dikes contain fragments which in part appear to merge into a crystalloblastic matrix having a pronounced flow structure. Other breccia dikes in this vicinity are filled with fragments of rocks of various kinds imbedded in a matrix replete with metamorphic minerals showing crystalloblastic features and marked flow alignment.

Breccias formed during metamorphism and exhibiting crystalloblastic features and flow structures cannot be adequately explained as orthomagmatic, but support the interpretation of movement of metamorphosed material. Since the mass flowage of this material can be included, in a more restricted sense, under the broad definition of rheomorphism, it is suggested that breccias developed under such conditions be termed rheomorphic breccias.

FIELD RELATIONS OF ARKANSAS BAUXITE DEPOSITS*

Mackenzie Gordon, Jr., Joshua I. Tracey, Jr., and Miller W. Ellis
U. S. Geological Survey, Washington, D. C.

Studies during the war indicate four principal types of bauxite deposits in the Arkansas bauxite region. Their occurrence is controlled by the source rocks, physiography of the ancient land surface on which they formed, and stratigraphic history of the region.

* Published with the permission of the Director, U. S. Geological Survey.

(1) Residual deposits on higher slopes of buried nepheline syenite hills have a lower zone, preserving the granitic texture of the original rock, and an upper concretionary zone. They are separated from fresh nepheline syenite by kaolinitic clay that, adjacent to the bauxite, appears massive or fragmental.

(2) Colluvial deposits on lower slopes along the buried edge of sediments of the Midway group have a lower zone locally preserving clay textures, a thicker concretionary zone above, and commonly upslope a siliceous hardcap. They grade into a surrounding kaolinitic envelope. Their deposition was contemporaneous with that of early Wilcox lignite, gray clay, and sand farther downslope.

(3) Alluvial deposits, composed of stratified, sorted, and cross-bedded pebbles, pisolites, and grains of bauxite, overlie and fill channels in colluvial bodies and tongue into the early Wilcox sediments.

(4) Alluvial deposits, mostly bauxite boulder beds, overlie residual deposits or early Wilcox sediments and tongue into later Wilcox sediments, particularly as the basal conglomerate of a dark chocolate-brown clay and sand unit that unconformably overlies the lignite, gray clay, and sand unit.

The first two types are the source of most of the ore in the region, but all four have been mined.

PROPERTIES OF THE EARTH'S CRUST BENEATH THE OCEANS

B. Gutenberg
Seismological Laboratory, Pasadena, Calif.

There are two major units of the earth's crust: (1) a larger, consisting of the continents, the bottom of the Indian and Atlantic oceans, with andesitic crustal material; and (2) the Pacific Basin with younger eruptive basaltic rocks. The boundary is the Marshall (andesite) line, and also the inner boundary of the earthquake belt surrounding the Pacific Basin. There are possibly outlying areas of Pacific structure such as the Caribbean and the area inside the southern Antillean arc and perhaps an area in the Arctic. Parts of the Pacific Ocean, near its borders, for example between South America and the Easter Island rise, or between the Mariannas and the Asiatic continent, show indications of "continental" layers.

Geophysical evidence for the discontinuity between the Pacific Basin and the surrounding "continental" area consists of great ocean deeps, negative gravity anomalies, and shallow earthquakes. This group of phenomena is followed on the continental side by a zone of earthquakes at depths of about 70 to 150 kilometers and active volcanoes; still farther inland shocks at increasing depths occur down to 700 kilometers. No other region shows this complete sequence of phenomena, nor are there earthquakes deeper than 300 kilometers anywhere else. Especially none of these phenomena occur along the coastal areas of the Atlantic and Indian oceans, nor is there any other known indication of a discontinuity between the ocean bottom there and the surrounding continents.

Other geophysical evidence for the difference in structure of the Pacific Basin and all other areas, including the bottom of the Atlantic and Indian oceans, is (1) The velocity of surface waves with periods of about 20 seconds is higher inside the Pacific Basin than anywhere else. (2) Surface waves travelling part of their way approximately along the boundary show a noticeable loss of energy, occasionally as high as 90 per cent. (3) Longitudinal waves reflected under the Pacific Basin have relatively smaller amplitudes than the corresponding waves reflected under the continents or under the other oceanic areas. (4) The earthquake belt marking the boundary of the Pacific Basin contains about 80 per cent of all earhquakes. (5) In the Atlantic, as well as in the Indian Ocean, active belts of shallow earthquakes, including occasionally major earthquakes, follow ridges inside these oceans; similarly, earthquake epicenters follow the mountain ranges of the Alpide belt. Except for the Hawaiian area, such belts are unknown in the interior of the Pacific Basin, where even very small shocks seem to be extremely rare.

REDWALL LIMESTONE ALONG THE SOUTHWEST MARGIN OF THE COLORADO PLATEAU, ARIZONA

R. C. Gutschick
Dept. of Geology, University of Notre Dame, Notre Dame, Ind.

The report is a continuation and extension of the work done in Yavapai County, Arizona. A line of stratigraphic sections along the southwest margin of the Colorado Plateau enables one to study the Redwall limestone oblique to the trend of the Paleozoic geosyncline in southeast Nevada. The formation is divisible into several distinct lithologic units. Discussion of facies, distribution of lithogenetic units, unconformable relations to underlying Devonian and overlying Carboniferous beds, and distribution of fossils throughout the formation will be included.

The area is critical toward an understanding of the closer relationship of Mississippian rocks to the north and the equivalent strata to the southeast extending into southern New Mexico. It also does not seem unlikely that the Redwall will make one of the most important reservoir units to the northeast.

STRATIGRAPHY OF THE ARBUCKLE LIMESTONE, ARBUCKLE MOUNTAINS, OKALHOMA*

William E. Ham
Oklahoma Geological Survey, Norman, Okla.

The Arbuckle limestone crops out in a triangular area 60 miles long and 27 miles wide, forming the core or about 60 per cent of the stratified rocks in the Arbuckle Mountains of south-central Oklahoma.

This limestone is subdivided, following Decker (1939), and mapped in eight formations, four in the Upper Cambrian and four in the Lower Ordovician or Canadian. Following Ulrich's nomenclature (1932) the Cambrian formations from the base upward are Fort Sill limestone, Royer dolomite, Signal Mountain limestone, and Butterly dolomite, the entire sequence having a maximum thickness of 1500 feet. At the western edge of the Arbuckle Mountains the limestone formations are thickest but thin eastward in inverse ratio to the dolomite formations. Locally around granite inliers in the central area and in nearly all the eastern area the Cambrian strata are exclusively dolomite. Two zones of the brachiopod genus *Billingsella*, one of *Finkelnburgia*, and one of *Apheoorthis* characterize the Cambrian formations.

Canadian formations from the base upward are McKenzie Hill limestone, Cool Creek limestone, Kindblade limestone, and West Spring Creek limestone. They aggregate 5200 feet; each formation is 1000 to 1500 feet thick. Chiefly limestone in the western Arbuckle Mountains, these formations likewise become dolomitized in part eastward, as well as showing an increase in the number and thickness of sandstone beds. The fauna is characterized by *Finkelnburgia* in McKenzie Hill; *Stichotrophia*, *Diaphelasma*, and *Lecanospira* in Cool Creek; *Archaeoscyphia*, *Triloechia*, and *Ceratopea* in Kindblade; and *Pomatotrema*, *Diparelasma*, and *Ceratopea* in West Spring Creek.

STRUCTURAL ANALYSIS OF THE WEST BORDER OF THE DURHAM TRIASSIC BASIN

John W. Harrington
4508 Hopkins Street, Dallas, Texas

The Durham Triassic Basin in Piedmont North Carolina is a lowland area floored with Triassic rocks and defined on the east and west by older Paleozoic slates and Carboniferous granites. A narrow

* Published by permission of the Director, Oklahoma Geological Survey.

strip along the western border of the sediments was mapped and the relationships of the pre-sedimentation and post-sedimentation structural features determined. A reconnaissance method of multiple-surface analysis was used to establish lineations in the Triassic-crystalline contact as buried fault-line scarps. The method was also applied to the graphic solutions of two otherwise indeterminate fault problems. A figure of 1800 feet was established as the probable minimum amount of erosional stripping since faulting. An integrated structural and geomorphic history for the formation and erosion of the western part of the basin is developed. Evidence is offered which suggests that the basin was never much wider than its present western limit and certainly did not extend as far west as the Dan River Triassic Basin.

HONDA FORMATION OF THE UPPER MAGDALENA RIVER BASIN, COLOMBIA, S. A.

Diego Henao-Londaño and Robert W. Fields
University of California, Berkeley, Calif.

A remarkable formation consisting of conglomerates, sandstones, and claystones is exposed in the Upper Magdalena River Basin of Colombia, South America. These rocks constitute the Honda formation of Hettner.

Lithologically the conglomerates, sandstones, and claystones are exceptionally uniform. The beds have been only slightly disturbed except along the flanks of the Magdalena basin. They represent a single depositional unit derived from the Central and Eastern Cordilleras. The sediments accumulated in a slowly sinking, widespread, lagoonal basin where sands and muds were deposited along meandering channels. The conglomerates indicate periods of flooding with resultant deposition of larger detrital material.

Until recently the Honda was believed to be confined to the Miocene. Fossil vertebrates from Coyaima in the lower reaches of the basin date that portion as Late Oligocene. A rich faunal assemblage from the La Venta region near the upper end of the basin indicates a Late Miocene age for that portion; thus this formation transgresses a known time boundary.

At the base of this formation is a recognizable angular unconformity as well as a lithologic disconformity. Overlying the Honda is a formation known as the "Mesa Capping". It lies conformable upon the Honda and is composed of rhyolitic tuff. It in turn is overlain by a Pleistocene conglomerate, the contact of which is a low angular unconformity.

SIGNIFICANCE OF EXPLOSIVE EVOLUTION FOR DIASTROPHIC DIVISION OF EARTH HISTORY*

Lloyd G. Henbest
U. S. Geological Survey, Washington, D. C.

The purpose of this symposium is to re-examine the foundation in paleontology for the theory that (1) diastrophism is periodic and synchronous on a world-wide scale; (2) diastrophism is a major control, if not the principal stimulus, for organic evolution; and therefore (3) diastrophism is the ultimate basis for dividing geologic time. The *distribution of genera and of evolutionary explosions in geologic time* has such a significant bearing on the methods of historical analysis in paleontology which led to the diastrophic theory that this was chosen as the subject of the symposium.

Though the diastrophic theory is doubted by many or is even regarded as a figment of circular reasoning, the theory has been a guiding principle in historical geology for many decades, and its acceptance is implicit in the stratigraphic classification and nomenclature of rock units.

Evolutionary explosions among the Foraminifera are numerous. They are distributed in tandem or in partly overlapping series in geologic time. No clear connection of these explosions with period-

* Published by permission of the Director, U. S. Geological Survey.

system boundaries is evident. Such connection as is evident tends to disappear when "missing links" and inaccuracies of the records enter consideration.

If the vertical ranges of genera of Foraminifera are plotted on the geologic time table, extinctions, initial appearances, and breaks in recorded ranges appear to bear a distinct relation to the period-system boundaries. It is the crux of our problem in this symposium to find out whether this pattern of distribution is as natural as appears or is an artifact of reasoning.

We are confronted with the necessity of getting down to fundamentals in geochronology and historical analysis. The effort at that task has disclosed sources of error and inaccuracies that cast serious doubt that the supposed segregation represents the original pattern of distribution. Moreover, the evidence for the diastrophic theory is based on so many unwarranted assumptions and is subject to such diverse interpretations as to make the truth of the theory a matter of speculation.

RECOGNITION OF THE LOWER ORDOVICIAN FORMATIONS IN THE SUBSURFACE OF CENTRAL TEXAS

Leo Hendricks
Texas Christian University, Fort Worth, Texas

The recognition of the Ellenburger group of Lower Ordovician formations in the subsurface must depend on petrologic criteria. The usable petrologic features in the order of decreasing importance are insoluble residues, grain size, and gross lithology. Comparison of these features in samples from type or standard sections of the Ellenburger with the same features in well samples results in a qualified correlation of the surface sections with the subsurface sections. The qualifications are:

(1) The petrologic features are not strongly diagnostic for distinguishing between the Gorman and Honeycut formations.

(2) The petrologic features are in some cases more subject to facies-control than the faunal features that are used in defining the formations.

The Tanyard-Gorman formation boundary is the most dependable horizon for correlating between surface and subsurface sections.

Cross sections show the extent to which subsurface stratigraphy of the Lower Ordovician can be interpreted in the Central Texas region, using the petrologic characteristics of the beds.

KINGSTON THRUST FAULT, INYO, SAN BERNARDINO COUNTIES, CALIFORNIA

D. F. Hewett
1460 Rose Villa Street, Pasadena, Calif.

In 1938, the author announced the recognition and mapping of an extensive thrust fault in the northwestern corner of the Ivanpah quadrangle, Southeastern California. The area has been re-examined recently, and parts have been remapped on a larger scale.

Four areas show remnants of a local dissected plate, and these are interpreted as parts of a plate roughly 15 by 35 miles. In the northwestern area, coinciding with the Kingston Mountains, about 8 miles in diameter, the sedimentary rocks of the late Precambrian Pahrump series, 7000 feet thick, rest discordantly on a smooth surface cut upon Archean granite gneiss. In the southwestern area, coinciding with the Shadow Mountains, roughly 5 by 8 miles, numerous blocks of Archean gneisses with steeply dipping foliation, as much as 1½ miles in maximum diameter, rest upon a flat surface and across the bedding of mid-Tertiary sediments. The northeastern area is a single hill made up of a block of Mississippian limestone 1½ miles long that rests upon mid-Tertiary sediments. The southeastern area, near Winter's Pass, southwest of Mesquite Valley, shows five blocks of lower Paleozoic Goodsprings dolomite (the largest more than a mile in diameter) that rest discordantly upon a flat surface cut on Archean granite gneiss.

The remnants of plates in the four areas appear to be parts of a plate that must have been at least

15 by 35 miles. As mid-Tertiary sediments and flows form part of the basement the thrust must have taken place in later Tertiary time.

ORBICULAR TINGUAITE DIKES NEAR BRYANT, SALINE COUNTY, ARKANSAS

Fred A. Hildebrand
The University of Chicago, Chicago, Ill.

Tinguaite dikes probably of Cretaceous age have intruded the northwest edge of a 400-square-mile province of phacolithic nepheline syenite intrusives in central Arkansas. The dikes are normal tinguaite and not metamorphosed Paleozoic pendants, which also occur in this alkaline province.

The dikes range from a few inches to 20 feet wide and occur in four parallel, linear zones 200 to 500 feet apart. The zones are traceable for at least 2500 feet in a northeast-southwest direction and disappear beneath overlapping Tertiary sediments.

The dike magma was viscous and moved horizontally as well as vertically as evidenced by (1) linear flow lines along the unaltered wall-rock contact; (2) tortuous flow lines and eddy currents adjacent to wall-rock protuberances and isolated, sparsely distributed, unaltered wall-rock fragments; and (3) cross-cutting flow lines analogous to schistosity in competent rocks. The wider dikes contain tabular phenocrysts of albite, while the narrower dikes contain small feldspathic spherulites.

The narrower dikes show unusually well developed orbicular structures heretofore not reported from alkaline rocks. The orbicules are 2 to 35 mm. in long dimension and consist of a tinguaitic nucleus and a peripheral banded zone about 1.5 mm. thick. In the peripheral zone bands of very fine-grained aegirite alternate with bands of mixed nepheline, sodalite, potash and soda feldspars. There is no mineralogical difference between the orbicules and matrix, although there is a textural difference in that aegirite occurs as isolated aggregates in the matrix.

Contemporaneity of the orbicules with the late cooling stage is shown by their elongation in the direction of flow, denting of one by another, nonintergrowth, truncation by flow lines, and enclosure of flow lines.

ALPHA ACTIVITY OF ROCKS AND SEDIMENTS BY SCINTILLATION COUNTING

H. D. Holland and J. Laurence Kulp
Lamont Geological Observatory (Columbia University), Palisades, N. Y.

Recent advances in nuclear instrumentation have permitted the utilization of scintillations produced on a zinc sulfide screen by alpha particles as a quantitative method for determining alpha activity. A scintillation counter is described in which a C-7132 RCA photomultiplier tube is adapted for low-activity samples by a truncated lucite cone. The counter is being applied to the study of the alpha activity and age determination of rocks and ocean-bottom sediments.

GLACIAL GEOLOGY OF THE WEST-CENTRAL WIND RIVER MOUNTAINS, WYOMING

G. William Holmes
Beloit College, Beloit, Wis.

During the Pleistocene the western Wind River Range was covered at least four times by a mountain ice cap which moved westward over the border scarp and terminated in lobate piedmont glaciers in the Bridger basin. The glacial sequence was preceded by the last major uplift of the mountains and a short erosion cycle, which cut the valleys nearly to their present depths. Buffalo till and outwash are now exposed at or near the level of the modern streams, indicating that the valleys existed in pre-Buffalo time. During the succeeding glacial stages, Bull Lake and Pinedale, the ice sheets moved approximately the same distance and deposited outwash in the pre-Buffalo valleys, which were repeatedly excavated by interstadial streams. The lithology and stratigraphy of the outwash and tills show that the Buffalo, Bull Lake, and Pinedale stages were compound. A separate gravel terrace

younger than the Buffalo but older than the Bull Lake may have been the outwash facies of recessional moraines of the Bull Lake stage or may represent a separate glacial stage. Bull Lake stage is represented by two distinct moraines and valley-train remnants, whose deposition was probably separated by a significant time interval. The color, weathering characteristics, mineral content, and size distribution of the two Bull Lake tills contrast sharply, and the deposition of the outwash was separated by an erosion phase. The Pinedale stage is composed of the main advance and a complex series of minor readvances, all represented by moraines and outwash deposits. Subsequently there have been at least two periods of relatively cool, moist climate in the mountains as indicated by a pair of low terraces, cirque moraines, and evidence for two phases of talus development.

STRATIGRAPHY OF THE CENTENNIAL REGION, BEAVERHEAD COUNTY, MONTANA

Fred S. Honkala
Geology Dept., Montana State University, Missoula, Mont.

The following formations were recognized in the Centennial region in Beaverhead County in southwestern Montana.

Age and name	*Thickness (feet)*
Quaternary	
Alluvium, sand dunes	
Tertiary	
High-level gravels (Pliocene?)	
Volcanic rocks (Miocene or Pliocene)	600±
Dikes and sills (?)	
Rhyolite flows	
Tuff and interbedded alluvial deposits	
Agglomerate or volcanic conglomerate	
Basalt flows	
Unnamed conglomerate (Paleocene?)	3000±
Cretaceous	
Aspen formation	3000±
Thermopolis shale	300
Kootenai formation	700±
Jurassic	
Morrison formation	181
Swift formation	21
Triassic	
Thaynes formation	138
Woodside formation	564
Dinwoody formation	358
Permian	
Phosphoria formation	229
Pennsylvanian	
Quadrant formation	402
Amsden formation	73
Mississippian	
Brazer limestone	772
Mission Canyon limestone	353
Lodgepole limestone	628
Devonian	
Threeforks formation	238
Jefferson dolomite	229
Cambrian	
Park shale	30
Meagher limestone	1007
Flathead quartzite	77
Precambrian (pre-Beltian)	
Cherry Creek series	
Total thickness recorded	12900±

Sections were located in the western part of the Centennial Range and the southern parts of the Gravelly and Snowcrest ranges. Pennsylvanian, Permian, and Triassic strata thicken westward and thin eastward from the Centennial region. In the Mississippian system the Brazer limestone or equivalents was separated from strata previously called the Madison group. High-level gravels were interpreted as residium of the once-widespread Paleocene(?) unnamed conglomerates or other coarse Tertiary clastics. On the basis of vertebrate evidence the top part, at least, of the beds in the Centennial Valley is termed Pleistocene. No Pleistocene glacial deposits were found.

BERYL AT MT. MICA, MAINE

Cornelius S. Hurlbut, Jr.
Harvard University, Cambridge, Mass.

The discovery of gem tourmaline at Mt. Mica, Maine, in 1820 was the beginning of nearly a century of gem mining at that locality. The last "pocket" opened in 1913 marked the end of active gem mining.

In June 1949, while mining feldspar a few hundred feet from the old gem workings, a new pocket was opened. This pocket is one of the largest found at Mt. Mica and measured about 20 by 4 by 5 feet. The lining of the pocket was mostly albite and muscovite, but a portion was of columnar beryl. Lying on the floor of the pocket were many colorless to white beryl crystals of unusual habit, completely terminated, and displaying many rare forms. Spectrographic analysis of these crystals show the presence of approximately 1.0 per cent lithium, 1.5 per cent cesium, and 0.1 per cent rubidium.

PLEISTOCENE PHYSIOGRAPHY AND SEDIMENTATION IN THE CADDO CANYONS OF OKLAHOMA

H. A. Ireland
Dept. of Geology, University of Kansas, Lawrence, Kans.

Field work, borings, and aerial photographs give information on Pleistocene drainage changes and periods of cut and fill related to the advance and retreat of the ice sheets in northern United States. Vertical-walled canyons with box heads were eroded by torrential water into soft red Permian sandstone and later filled with Pleistocene sediments. Bore holes to bedrock prove the present valley fill to be 30 to 60 feet thick. The former fill was about 60 to 100 feet. At least three terraces are observable. Soil profiles and muck layers were encountered in the borings.

The periods of entrenchment are attributed to increased rainfall in southern areas which occurred with the greater humidity during the early part of each glacial stage. Deposition occurred during the retreat of the ice sheets and continued into interglacial stages when the climate was less humid. A relic flora of a former cooler more moist climate has been identified. Piracy caused by entrenchment of channels is common resulting in complex relic valley systems.

Similar canyons are present over about 3000 square miles where similar bedrock is at the surface. The area is part of a plateaulike interfluve between the Washita and Cimarron rivers on which the North and South Canadian rivers flow at levels 150 feet higher than the Washita or Cimarron rivers.

DEVELOPMENT AND USE OF MULTIPLE PACKERS BY THE BUREAU OF RECLAMATION FOR GROUND-WATER OBSERVATION IN ENGINEERING GEOLOGY

W. H. Irwin, T. P. Ahrens, A. C. Barlow, and E. D. Rhoades
U. S. Bureau of Reclamation, Denver, Colorado; U. S. Bureau of Reclamation, Denver, Colorado; U. S. Bureau of Reclamation, Denver, Colorado; U. S. Bureau of Reclamation, Coulee Dam, Washington

The development of the Columbia Basin Project in the State of Washington made necessary the study of the various ground-water tables contained within the project area and determination of probable effects of the ground-water on engineering structures and the effects of the structures on the ground-water tables. In numerous portions of the area perched, normal, and artesian water-tables were encountered in a single hole. There was need for some method of periodically measuring several water-table levels in a single drill hole to permit an adequate study and mapping of the complex ground-water conditions, and to avoid the expense of drilling an unusually large number of deep holes. A device termed a multiple packer was developed. It is similar in appearance to an ordinary packer but is constructed so that several small-diameter copper tubes can be passed through it to measure the elevation of the water tables or the pressure head of aquifers below the packer. Each aquifer is isolated from other aquifers in the same hole by a multiple packer, and as many as 11 separate water tables can be measured in a single hole 3.5 inches in diameter.

The device, on which an application for patent has been made by E. D. Rhoades, includes several variations in design to facilitate installation. The multiple packer has been developed primarily for use in consolidated rock formations, but its adaptation to unconsolidated formations is being studied.

ROLE OF YTTRIUM AND OTHER MINOR ELEMENTS IN THE GARNET GROUP

Howard W. Jaffe
U. S. Bureau of Mines, College Park, Md.

Several minor and trace elements, notably yttrium, scandium, and zinc are very common in garnets. The frequent occurrence of several of these in particular varieties of garnet suggests isomorphism. Yttrium, heretofore considered a rare constituent of garnets, is very prevalent in spessartites. It occurs in concentrations of greater than 2 per cent Y_2O_3 in a few manganese-rich garnets. The frequent association of yttrium and manganese in spessartites suggests that ions of Y^{+3} with an ionic radius of 1.06 A have replaced ions of Mn^{+2} having an ionic radius of .91 A, the values being those of Goldschmidt. Scandium is most abundant in pyropes, and Sc^{+3} with an ionic radius of .83 A may substitute for ions of divalent Mg (.78 A) or possibly for divalent Fe (.83 A) if sufficient almandite is present. Zinc is a common trace element in manganese, iron, and magnesium-rich garnets, and ions of divalent Zn (.83A) may proxy for those of divalent iron. Other trace constituents detected in garnets include Ga, Ti, Na, Li, Dy, Gd, La, Ce, Nd, Pr, Sr, Ba, F, H_2O, and Cb. Their hypothetical isomorphous relations to the major constituents are discussed. Included in the data are 7 new quantitative yttria determinations, visual spectroscopic analyses of more than 70 garnets, and spectrographic analyses of 2 yttria precipitates obtained from spessartites.

LITHIUM-BEARING PEGMATITES NEAR WICKENBURG, ARIZONA

Richard H. Jahns
California Institute of Technology, Pasadena 4, Calif.

Dikes, sills, pods, and irregular, branching masses of pegmatite are exposed in the White Picacho mining district, northeast of Wickenburg, Arizona. These pegmatites are enclosed by coarsely crystalline metamorphic rocks of Precambrian age and locally are overlain by Tertiary volcanic and sedimentary rocks. Most are closely associated with other, more abundant pegmatites that do not appear to contain lithium minerals.

Nearly all the pegmatite bodies show well-developed zoning. Their outer parts are medium- to coarse-grained granitoid aggregates of perthite and quartz, with subordinate sodic plagioclase and muscovite. Their inner parts are much coarser and commonly consist of anhedral quartz, with or without euhedral perthite, or of coarse, blocky perthite with relatively little quartz. Other interior-zone combinations include quartz-spodumene, quartz-amblygonite, quartz-perthite-amblygonite, and quartz-spodumene-amblygonite. Fracture fillings and some masses of replacement origin also occur in the pegmatites, but most are very small and discontinuous.

The pegmatite minerals thus far identified are microcline, quartz, sodic plagioclase, muscovite, biotite, garnet, amblygonite, lepidolite, spodumene, allanite, apatite, beryl, beyerite, bismuth, bismuthinite, bismutite, cassiterite, columbite-tantalite, fluorite, hureaulite, lithiophilite-triphylite, magnetite, purpurite, strengite, sulfides, tourmaline, triplite, and zinnwaldite. Later hypogene mineralization, probably not genetically related to the pegmatites, is represented by fracture-controlled concentrations of chalcopyrite, galena, molybdenite, pyrite, pyrrhotite, scheelite and powellite, and sphalerite, occurring singly or in combination. With some of these concentrations are anglesite, cerussite, chrysocolla, cuprite, mimetite, native silver, pyromorphite, vanadinite, and wulfenite.

IRON FORMATION AND ASSOCIATED ROCKS OF THE IRON RIVER DISTRICT, MICHIGAN

Harold L. James
U. S. Geological Survey, Washington, D. C.

The iron formation of the Iron River district is part of a Precambrian sequence characterized by high iron and rather unusual mineralogy. The iron formation, where unoxidized, consists largely of

interlaminated chert and siderite. It is underlain by graphitic slate containing about 40 per cent pyrite in the form of very finely disseminated grains. Graywacke overlies the iron formation with at least local disconformity; the rock consists of clastic grains in a matrix of siderite or iron-rich chlorite. Above the graywacke is a magnetic ironstone, a laminated rock that now consists of siderite, magnetite, chert, and iron-rich chlorite, with each layer being an intermixture of two or more of these constituents. The average iron content of the rock sequence including the iron formation is approximately 20 per cent. The rocks are only slightly metamorphosed, although structurally the area is one of complex, tight folding.

It is concluded that the high iron content is primary. The rocks are believed to be the products of an epoch of iron-rich sedimentation in which the specific mineral formed—pyrite, siderite, or iron silicate—depended upon the immediate depositional environment. Inasmuch as the formation of iron-rich minerals persisted despite extensive physical changes in both the basin of deposition and the adjacent land area, the ultimate cause for such an epoch is one which transcended such factors.

TRIASSIC TO TERTIARY STRATIGRAPHY NEAR CERRO DE PASCO, PERU

William F. Jenks
University of Rochester, Rochester, N. Y.

Near Cerro de Pasco an eastern facies of lower Mesozoic limestones 9500 feet thick is brought close to beds on the west of the same age and one quarter as thick by thrust faulting and close folding. The strata involved are Upper Triassic and may extend into the lower Liassic. Fossils are abundant but conclusive only as to the oldest beds (Norian). Original difference in thickness of the two facies is due to abnormal accumulation in a narrow north-trending negative zone east of Cerro de Pasco, with rapidly diminishing thickness and time continuity away from this zone to the west.

Tertiary strata, which have been confused in recent works with the Triassic, accumulated in low-level intermontane basins on folded and faulted Mesozoic and Paleozoic formations. Strong deformation at the end of the Cretaceous was followed, after the accumulation of Tertiary continental deposits, by thrust faulting and isoclinal folding in the early Tertiary. One member of the Tertiary sequence is a fanglomerate, study of which suggests a short period of movement between the two major ones. Minor warping is indicated toward the close of the Permian and Jurassic periods. Intrusive and extrusive igneous activity apparently closely followed early Tertiary deformation.

PERMIAN CALCAREOUS ALGAE FROM THE APACHE MOUNTAINS, TEXAS

J. Harlan Johnson
Colorado School of Mines, Golden, Colo.

Algae occur through a considerable thickness of beds in the Apache Mountains. Locally they are so abundant as to be the main constituent of the limestones. The forms described include red algae (Solenopora), green algae, both Codiaceae and Dasycladaceae and lower tubular and filimentaceous forms. Dasycladaceae are the most abundant and include not only *Mizzia* but several other genera. Of especial interest is the occurrence of several species of *Gymnocodium* as this is common in most areas of Permian deposits but has not been previously described from the Western Hemisphere.

GEOLOGY OF THE HELVETIA MINING DISTRICT, PIMA COUNTY, ARIZONA

Vard H. Johnson
506 Federal Building, Salt Lake City, Utah

Helvetia, one of the minor copper mining districts of Arizona, shows the complex structural relations typical of the mining areas of Southern Arizona. Paleozoic sediments, mostly calcareous, were intruded by a post-Permian granite which was, in turn, intruded by a Tertiary alaskite granite. Cretaceous sediments, formed largely of the older igneous material, were faulted and intruded by the alaskite

granite and by diorite dikes. Dikes of diabase and basalt are present also. Normal and reverse faulting accompanied both major intrusions. Copper, silver, lead, zinc, tungsten, and molybdenum have been mined at Helvetia. All the ore bodies are in the contact-metamorphic zone or in replacement bodies and fissure veins near the contact. Local evidence is insufficient to show whether the ore deposits are genetically related to the emplacement of the post-Permian granite or the alaskite granite, as the ore bodies occur at the contacts of both intrusives with calcareous sediments.

HYDROXYL IN MINERALS

W. D. Keller and E. E. Pickett
University of Missouri, Columbia, Mo.

Water may occur in minerals as mechanically held, evaporable "free" water, as loosely held "water of crystallization", and as more tenaciously held "water of constitution". Free water and tightly held hydroxyl (OH) may be differentiated in powdered minerals by their absorption of the infra-red spectrum.

The OH group may be singly (monomeric) bonded to other elements in the crystal and therefore vibrate freely. Dimeric and polymeric bonding, where two or more OH groups share resonating mutual bonds, are indicated as also present by infra-red absorption. Examples of the several bond types are illustrated by absorption spectrograms of clay minerals, opal, zeolites, and other hydrated minerals.

ALTERATION FEATURES AT SILVER BELL, ARIZONA

Paul F. Kerr
Dept. of Geology, Columbia University, New York, N. Y.

Silver Bell offers advantages for the study of hydrothermal alteration connected with copper mineralization. Copper deposits partly explored but as yet unmined are available for the correlation of surface and underground data. A variety of igneous and sedimentary rock types in widely varying degrees of alteration provide field criteria to correlate with known trends in mineralization.

Previous investigations have furnished a geologic map upon which the alteration pattern may be superimposed. This is particularly important in an area of complex sedimentary, igneous, and structural history.

Four rock types are involved in the pattern of hydrothermal alteration: alaskite, dacite, dacite porphyry, and quartz monzonite. In each, various stages may be found which start with the unaltered rock, pass through successive stages of attack, and ultimately terminate in complete replacement by clay minerals, sericite, and quartz in varying proportions. Field and laboratory studies of the different stages when correlated with data on the nature and distribution of copper mineralization yield significant information on the trend of the principal zone of mineralization, the more highly productive areas, and the areas which appear largely barren. In the Silver Bell area such determinations have reached a point where alteration criteria may serve as a guide in drilling.

In addition to the economic applications the alteration criteria are of considerable assistance in determining the distribution of igneous rock units. In all but the final stages of complete replacement the original rock types may be recognized on the basis of mineralogical composition and texture. Such study has also aided in verifying and extending the interpretation of the structural pattern.

REVIEW OF COAL RESEARCH 1948–1949

R. M. Kosanke
Illinois State Geological Survey, Urbana, Ill.

The literature for 1948–1949, exclusive of resource studies, is reviewed. In some cases, foreign publications prior to 1948 are included because they have been made available to us during the past year. For convenience, the publications have been classified under the following topics: origin and metamorphism of coal, coal petrography, paleobotany, geochemistry, and coal mining. This is in line with

suggestions made at the March 1949 meeting of the Coal Research Committee of the Society of Economic Geologists held at the Bureau of Mines, Pittsburgh, Pennsylvania.

SURFACE AREA OF DEEP-SEA SEDIMENTS

J. Laurence Kulp and Donald R. Carr
Lamont Geological Observatory (Columbia University), Palisades, N. Y.

The application of the radioactive inequilibrium method of age determination to unconsolidated ocean sediments is based on the preferential adsorption of ionium and radium ions on the surface of precipitating particles. The adsorptive properties of the sediment depend both on the chemical nature and the surface area of the particles. The chemical nature of the sediments can be ascertained from the mineralogy. For a constant mineral type the number of ions adsorbed will be proportional to the surface area. Therefore a knowledge of the mineralogy and the surface area of the material will permit the use of sediments of varying lithology in age determination by the radioactive inequilibrium method.

The surface area of about 50 representative core samples has been obtained by the Emmett-Brunauer gas adsorption method. Values range from 2 square meters per gram for fine red silt to 40 sq.m./gm. for very fine inorganic calcium carbonate. Deep-water red clay has a surface area of about 25 sq.m./gm., while the more common green clay from shallower water ranges from 10 to 15 sq.m./gm.

Implications of this quantitative information in age determination and ocean-bottom geology will be discussed.

SCHEME OF THE CHEMISTRY OF THE ORE VEINS BASED ON QUALITATIVE SPECTROGRAPHIC ANALYSIS

Jan Kutina
Dept. of Mineralogy, Charles University, Praha, Czechoslovakia

The chemistry of the ore veins is represented by a diagram showing all stated elements including the trace quantities, with reference to the ore veins from St. Anthony de Padua mine near Poličany, southwest of Kutńa Hora (Bohemia).

(1) The paragenetic sequence of all discussed minerals as determined in polished sections is shown diagrammatically. (2) From spectrographic analyses of the minerals the elements present have been assigned by visual estimation to three categories: large, small, and trace. (3) In the diagram showing the chemistry of the ore veins the elements are on the ordinate, and on the abscissa the variation in amounts of the elements during various periods of crystallization. Also noted is the abundance of the various minerals in different generations.

From the diagram one can observe the quantitative relationship of elements at different temperatures during the genesis of the ore veins. For example, arsenic is concentrated at the highest temperatures, and at the lower temperatures it occurs in traces only; in general the reverse is true with antimony. The chief concentration of many elements is preceded in the succession by trace amounts in the older minerals and by traces in the younger ones. Some of the elements appear to be unaffected by temperature—*e.g.*, iron.

The dependence upon temperature, however, must be considered with possibilities of isomorphous substitution (Cd, Ga, In, etc.) and the problems of exsolution.

METALLURGICAL LIMESTONE RESERVES

Kenneth K. Landes
Ann Arbor, Mich.

"Metallurgical limestone" as here used includes both limestone and dolomite which are of such quality as to be suitable for blast-furnace flux, open-hearth flux, furnace linings, lime burning, and

chemical manufacture. The specifications vary with the use, but within any one use classification there is very little latitude possible in regard to either chemical composition or physical character. Contrary to usual opinion the reserves of limestone suitable for metallurgical operations are by no means unlimited. With very few exceptions the high-grade limestone deposits being exploited today will be exhausted during the next 50 years.

CYCLE OF DEPOSITION IN THE SALADO FORMATION OF THE PERMIAN OF NEW MEXICO AND TEXAS*

Walter B. Lang
U. S. Geological Survey, Washington, D. C.

In the process of evaporation of marine sea water the normal sequence of precipitation is iron oxide, calcium carbonate, calcium sulfate, sodium chloride, and the potassium-magnesium chlorides and sulfates. Under the ideal geologic conditions that pertained during the latter part of the Permian in the Southwest, the deposits were so arranged within the basin of deposition. The deposits of the Salado formation represent the latter half of this sequence of deposition. The elementary cycle of deposition in the Salado formation is the anhydrite-halite couple. In addition, a silt member is present at many places. The sylvite and related potash beds, though of great economic importance, are only incidentals within this major couple. Polyhalite is also present in these deposits. It is believed that polyhalite is here a secondary mineral formed diagenetically after anhydrite.

PERMIAN AMPHIBIANS FROM THE ABO FORMATION OF NEW MEXICO

Wann Langston, Jr.
Museum of Paleontology, University of California, Berkeley, Calif.

The University of California collection of Abo amphibians from Rio Arriba County, New Mexico, contains the following forms: *Chenoprosopus* Mehl, a small eryopid; *Platyhystrix* Williston, a zatrachid; *Pantylus* Cope; and an *Archeria*-like embolomere. All these forms are somewhat smaller than related species from the Clear Fork and Wichita beds, and as a unit the fauna appears to be somewhat more primitive than those from Texas localities.

Chenoprosopus appears to be a primitive rhachitome closely allied to *Edops*. The apparent absence of a parietal foramen in adult individuals and the slender form of the skull suggest that the genus represents a sterile side-branch from the *Gaudria-Edops* line. Postcranial elements are unknown.

Characteristic *Platyhystrix* spines are associated with peculiar double-headed and highly sculptured ribs. Several cranial fragments bear similar nodular sculpture and indicate that *Platyhystrix* is distinct from *Zatrachys*. Vertebrae of incomplete articulated zatrachid skeletons are typically rhachitimous and bear short robust spines.

A lower jaw of *Pantylus* contains a single large anterior acrodont tooth in each ramus separated from the smaller lateral teeth by a wide diastema. A slightly smaller tooth lies directly upon the solidly fused symphyseal suture.

Embolomerous amphibians heretofore unreported from the Abo formation are represented by a few vertebrae and ribs of an *Archeria*-like individual.

GEOMETRY OF TRICLINIC ADULARIA

Fritz Laves
Dept. of Geology, University of Chicago, Chicago, Ill.

Thin sections of adularia show some optical deviations from monoclinic symmetry that are negligible at the core of the crystals, increase toward the surfaces, and reach a maximum in the area

* Published by permission of the Director, U. S. Geological Survey.

of the acute angle (110)∧(1̄10). X-ray pictures of this area show that the (110) and the (1̄10) sectors bear a symmetrical relationship to the plane (010) which is the symmetry plane in monoclinic adularia. The composition plane between these sectors is irregular in direction averaging close to (100) with an error of about 10°; it is always parallel to the *c* axis.

X-ray precession pictures of material from Mt. Vesuvius, Italy, showed definite triclinic symmetry. Pictures were made of I, the (110) sector, and II, the (1̄10) sector. Precession axes were [100], [1̄00], [001], [00ī], [101], [1̄0ī].

Results: (I) $\alpha = 89°50' \pm 5'; \beta = 116°; \gamma = 90°39' \pm 5'$
(II) $\alpha = 90°10' \quad ; \beta = 116°; \gamma = 89°21'$

The relationship between parts I and II fulfills no known law. They are simply symmetrical to the (010) symmetry plane of "monoclinic" adularia. This fact, plus other considerations, implies that the adularia originally grew as a monoclinic crystal and later changed progressively from the surface inward to a triclinic modification. X-ray as well as optical measurements of the core of the crystal with the triclinic system of co-ordinates given above showed no deviation from monoclinic symmetry.

Heating at 1000°C for 4 days produced some optical change; the crystal became "less triclinic". The x-ray pictures still showed triclinic symmetry.

The combination of the optical and the x-ray measurements shows that the optical n_a axis which is close to the geometrical *a* axis in monoclinic adularia deviates in triclinic adularia in the same direction as the geometrical *a* axis. The geometrical deviation is 39′ ($\gamma = 90°39'$); the corresponding optical deviation is about 10°.

NEWLY DISCOVERED EXTENSION OF THE LABRADOREAN ICE SHEET INTO EASTERN IOWA DURING THE TAZEWELL SUBSTAGE OF THE WISCONSIN STAGE

Morris M. Leighton and Paul R. Shaffer
Illinois Geological Survey, Urbana, Ill.; University of Illinois, Urbana, Ill.

Evidence will be presented indicating that the Labradorean ice sheet crossed the Mississippi River Valley from Illinois into Iowa between Clinton, Iowa, and Princeton, Iowa, during the Tazewell substage of the Wisconsin stage.

The width of the lobe from North Clinton (Lyons) to Princeton was about 16 miles. Upstream a large temporary glacial lake was formed, recorded by remnants of sediments that approximately accord with the Goose Lake diversion channel 10 miles west of Clinton.

During Sangamon interglacial time the Mississippi River flowed south and southeast from Clinton to the Big Bend of the present Illinois River Valley and down the lower Illinois. This lowland doubtless facilitated the above-mentioned extension of the Wisconsin glacier which diverted the Mississippi River to its present southwesterly course. The advancing ice later blocked the Meredosia segment and shifted the Mississippi into the Cordova-Hampton gorge. Later the waters from the lake upstream spilled through the Goose Lake channel and apparently discharged along the southwest border of the ice lobe to the Cordova-Hampton gorge.

South of the protruding ice lobe, evenly bedded silts and sands were deposited to an elevation of about 640 feet, presumably controlled by a low col between Fort Madison and Keokuk, Iowa, where the present valley is unusually narrow.

When the ice dam at Clinton eventually gave way and the waters of the lake upstream were released, a torrent apparently resulted, cutting down the low col between Fort Madison and Keokuk and sweeping out the silt filling.

LOESS FORMATIONS OF MISSISSIPPI VALLEY

Morris M. Leighton and H. B. Willman
Illinois Geological Survey, Urbana, Ill.

Three loess formations are widespread in Mississippi Valley—the Loveland loess of pro-Illinoian age, the Farmdale loess, pro-Wisconsin, and the Peorian loess, a composite of the post-Farmdale

loesses. The stratigraphic positions and ages of these loess formations are determined by their relationships to drift sheets of known ages and by profiles of weathering. Variations in thickness, grain size, composition, and topographic position demonstrate derivation by wind from the major valley trains. Faunal content confirms. Secondary processes produced minor modifications. The evidence does not support origin of any part of the loess deposits by the process of "loessification" advocated by R. J. Russell and H. N. Fisk.

Interpretation of the conditions of loess formation and recognition of stratigraphic succession are critical to unraveling the Late Cenozoic history of the Mississippi Valley. Consideration of the tops of loess deposits by Fisk and others as terrace surfaces has led to erroneous correlations of physiographic surfaces between central Louisiana and the loess-covered uplands along the east side of the Mississippi River, and to misconceptions of physiographic history. The hypothesis of loess as "loessified" alluvial silts requires that Pleistocene rivers covered much greater areas and flowed at much higher levels than does the eolian concept.

PHYSICAL ANALYSIS OF POLYCOMPONENT GARNET

S. Benedict Levin
Signal Corps Engineering Laboratories, Fort Monmouth, New Jersey

The widespread occurrence and compositional variation of garnet, in relation to the character of the rock facies in which it is indigenous, make it a useful diagnostic mineral in many petrologic problems. This places a premium on methods for the relatively rapid and accurate determination of garnet composition, especially where many specimens or very small amounts of clean material are involved. For detailed compositional correlation the 3-component solutions afforded by the triangular diagrams of Ford and Winchell do not suffice, since most garnet specimens (probably over 85 per cent) contain 4 or 5 of the theoretical component "molecules" in significant amounts, that is, one mol per cent or more. Good 4-component solutions are afforded by the measurement of 3 physical properties which are independent (non-parallel) functions of the compositional variation, viz: index of refraction n, specific gravity G, and lattice constant a_o. These values may readily be applied to an algebraic solution or to the tetrahedral graphical solution of Philipsborn and (with the same data) will yield quantitative results considerably better than the geometric estimates of Stockwell.

For most occurrences, however, only a 5-component solution in terms of pyrope, almandite, spessartite, grossularite, and andradite will account for 99 per cent or more of each garnet specimen. Such solutions are afforded by supplementing the 3 physical measurements (n, G, a_o) with a rapid partial chemical analysis for either MnO or FeO. With these 4 measured quantities, and the summation to 100 per cent providing the fifth, it is possible to set up and solve 5 simultaneous equations to yield the values of the 5 unknowns—*i.e.*, the molecular proportions of the 5 component molecules. In connection with a recent study of Adirondack garnets, a general solution of the 5 simultaneous equations has been made and the algebraic calculations thereby abbreviated to about 20 minutes of machine calculating. In laboratories having the usual equipment, an x-ray diffraction camera, thermally calibrated high-index liquids, a micro-pycnometer, etc., this composite method results in considerable saving of time over wet chemical methods, especially where many analyses are needed. By measuring N to $\pm.001$, G to $\pm.005$, a_o to $\pm.002$ Å, and MnO to $\pm.2\%$, results accurate to ± 1 mol per cent are obtained. Examples from the author's recent work are cited.

STRUCTURE IN THE ARIZONA-NEVADA BOUNDARY AREA*

Chester R. Longwell
Yale University, New Haven, Conn.

West of the Grand Wash Cliffs and north of the Colorado River, the Paleozoic section thickens toward the axis of the Cordilleran geosyncline, and Mesozoic systems total several thousand feet of

* Published by permission of the Director, U. S. Geological Survey.

thickness. This thick sedimentary sequence ends abruptly on the south, and in a wide belt east and west of the river, extending southward nearly 150 miles, no trace of Paleozoic and Mesozoic strata has been found. Bedrock in this large area consists of gneiss, schist, and granite, of volcanic and igneous rocks supposed to be chiefly or wholly post-Mesozoic in age, and of local clastic deposits. Over a large part of the area between Hoover and Davis dams, the volcanic rocks are divisible into four distinctive units that represent successive episodes of eruption.

West and north of the river belt, great thrust faults affect the thick section of sedimentary formations. No thrusts are recognized in the river belt of volcanic and Precambrian rocks, although a steep reverse fault of large displacement extends for many miles along the west base of the Black Mountains. Many normal faults, both large and small, trending generally north and northwest, bound blocks that for the most part are tilted, some at large angles. In the northern part of the belt, tilting is consistently to the east, with cumulative downthrow on the west sides of faults. South of Black Canyon, through a distance of about 25 miles, this structural habit is reversed. In the vicinity of Davis Dam the prevailingly eastward tilt is resumed.

PETROLOGY OF BIG BEND NATIONAL PARK, TEXAS

John T. Lonsdale and Ross A. Maxwell
University of Texas, Austin, Texas; Big Bend National Park, Marathon, Texas

In the southern part of the Big Bend region, Texas, including the Big Bend National Park, is a great development of early Tertiary intrusive igneous rocks and a thick section of pyroclastics and lava flows. The latter apparently once covered a large part of the area. Intrusive masses are mainly restricted to the southern part of the region but are abundant also in the Davis Mountains to the north.

The intrusive masses include a few larger plutons, stocks (?), and laccoliths emplaced under a cover of 3000–4000 feet of Tertiary and/or Cretaceous strata. There are many smaller laccoliths, sheets, sills, and dikes.

The intrusive rocks are mainly fine-grained with a few of coarser texture. Forty-two chemical analyses show a nearly complete gradation from silicic to mafic types. The suite is alkalic and generally sodic with phosphorus and titanium prominent in the intermediate and mafic members. These also exhibit considerable differentiation *in situ* with prominent formation of analcime. The silicic members do not exhibit marked differentiation but a considerable variation from mass to mass. Possibly more than one sequence of intrusion is present. In the park area silicic sodic intrusives were late in the sequence.

The lava flows do not show the extensive variation of the intrusive rocks. They include, however, similar alkalic and other types and belong in the same suite. Vents have not been specifically determined, but certain irregular pluglike masses in the southern Chisos Mountains probably were feeders for part of the rhyolitic lavas.

NOTE ON A NEURAL SPINE OF A PERMIAN ARMORED AMPHIBIAN

Ernest Lundelius
Rt. 5, Box 83, Austin, Texas

The discovery of a nearly complete, ornamented neural spine of an amphibian in the Wichita beds in Rattlesnake Canyon, Archer Co., Texas, led to a review of the literature on the ornamented neural spines of armored Amphibia and study of the specimens in the collection of the Bureau of Economic Geology, University of Texas. The author believes that several genera and species should be combined into one form showing a gradational sequence from a low, triangular type of spine to a high narrow type.

PETROLOGY OF METAMORPHIC ROCKS, MIGMATITE, QUARTZ DIORITE, AND MINERAL DEPOSITS, WARN BAY-TOFINO INLET AREA, WEST COAST VANCOUVER ISLAND, BRITISH COLUMBIA*

W. J. Lynott
St. Louis University Institute of Technology, St. Louis, Mo.

This paper is based on field work for British Columbia Department of Mines during summers of 1946 and 1947 supplemented by office and laboratory studies at Princeton University during 1947 and 1948. The mountainous area centers at 49°13′ N. Lat. and 125°40′ W. Long., about 15 miles by water from Tofino. Irregular outlines of the area mapped geologically, scale ½ mile to 1 inch, lie within a larger area about 9 miles square of which coast line only had been mapped, scale 8 miles to 1 inch.

Results of this work include description of rock types, and modes of mineralization, within an area containing gold-quartz veins, high-temperature copper replacement deposits, and small copper-nickel-cobalt-platinum deposits.

Bedrock is mapped as two major units:

(1) Lower Mesozoic and possibly earlier rocks subdivided into
  (a) stratigraphic unit under lime-bearing formation
  (b) lime-bearing formation
  (c) chiefly volcanic types
(2) Jura-Cretaceous (Coast Range) quartz diorite and related types

Features of metamorphic rocks, migmatite, intrusive rocks, and mineral deposits are described. Observations in the map area indicate that development of migmatite, in part at least, began with regional metamorphism prior to batholithic emplacement and continued during intrusion and consolidation of the batholith. Banded migmatites formed from intrusion and/or replacement of thin-bedded metasediments and intercalated volcanic and pyroclastic rocks underlying lime-bearing formation.

With minor exceptions mineral deposits are related more closely in space to apically truncated stocks than to the batholith or migmatite zones.

ACCURACY OF THE LEAD METHOD FOR THE ABSOLUTE MEASUREMENT OF GEOLOGIC AGES

John Putnam Marble
National Research Council, Washington, D. C.

The "lead method", involving the determination of the ratio of Pb to U + Th by chemical analysis, and its correction for "common" Pb content by measurement of ratios of the Pb isotopes is the most widely used method for the absolute measurement of geologic ages. The method is based upon: (1) the constants of radioactive decay; (2) their constancy throughout geologic history; (3) chemical analysis of a suitable mineral for Pb, Th, U; (4) separation of the contained Pb, free from interfering elements, in a form suitable for the accurate measurement of the ratios of its isotopes; (5) measurement of these ratios; (6) and, very important, adequate laboratory and field study of the mineral used, to determine presence of leaching, enrichment, and the like. Present methods for the study of these points, and of their accuracy, will be discussed.

PRELIMINARY ACCOUNT OF THE NATURALLY OCCURRING ANTIMONY OXIDES

Brian Mason and Charles J. Vitaliano
Dept. of Geology, Indiana University, Bloomington, Ind.

Among the naturally occurring antimony oxides the following phases have been recognized: senarmontite, Sb_2O_3, isometric; valentinite, Sb_2O_3, orthorhombic; and an isometric phase with the

* Published with the permission of the Chief Mining Engineer, British Columbia Department of Mines.

pyrochlore structure, and with the ideal composition $Sb^{III}\,Sb^{V}_{2}O_6(OH)$. The latter phase is by far the most common of the oxidation products of antimony minerals. Its composition and physical properties are exceedingly variable, owing to the ready substitution of the antimony by other elements, and to the incomplete filling of some of the lattice positions. This appearance of vacant lattice positions is evidently largely responsible for the extreme variability of density and refractive index in this phase. Recorded values for the density range from 3.5 to 5.6, and of the refractive index from 1.6 to 2.1. This phase includes both the cervantite and stibiconite of the mineralogical texts. The phase Sb_2O_4 has not been recognized among the naturally occurring antimony oxides, and its occurrence is questionable; the material described as cervantite, with the supposed formula Sb_2O_4 (theoretical composition is Sb = 79.2, O = 20.8), is actually the above-described isometric phase (theoretical composition for $Sb^{III}\,Sb^{V}_{2}O_6(OH)$ is Sb = 76.4, O = 21.8, H_2O = 1.88).

GENERAL GEOLOGY OF BIG BEND NATIONAL PARK, TEXAS

Ross A. Maxwell and John T. Lonsdale
Big Bend National Park, Marathon, Texas; University of Texas, Austin, Texas

The Big Bend is the name, loosely applied, to that portion of West Texas where the Rio Grande makes a big bend between Long. 102°50′ and 104°50′. Big Bend National Park includes only the southern portion of the area.

The Chisos Mountains, the dominant topographic feature, rise abruptly above a wasteland plain where erosional processes under semiarid conditions have produced a rugged topography. The surface is underlain by Paleozoic and Cretaceous sedimentary strata; Tertiary pyroclastics, tuffaceous sediments, lava flows, and intrusive masses; and alluvial debris. The Upper and Lower Cretaceous rocks, some 4000 feet in thickness, reflect regional problems common to West Texas, but for the most part can be loosely correlated with the standard Cretaceous section of Texas. The Tertiary includes 2000 feet of volcanic materials, unconformable upon the Cretaceous, and crops out in isolated areas over both highlands and lowlands indicating an original extensive sheet. The alluvial debris aprons represent two periods of deposition of post Tertiary volcanic age, derived chiefly from local highlands.

The Park area has been complexly folded and faulted. The most prominent structural feature is a sunken block, about 40 miles wide, depressed 4000 to 6000 feet, and bordered laterally by tilted fault blocks and asymmetrical folds. The central portion of the rift has been elevated by the Chisos Mountains pluton and associated intrusive masses that have changed a rather simple structural picture into a complex series of folds and fault blocks.

SEDIMENTARY BASINS OF ARIZONA AND ADJOINING AREAS

Edwin D. McKee
Dept. of Geology, University of Arizona, Tucson, Ariz.

An analysis has been made of the thickness of sediments accumulated in various parts of Arizona and adjoining areas during each of the periods of geologic history. From these and other sedimentary data conclusions are drawn concerning the times and places of crustal movement in the region.

For the Paleozoic and Mesozoic eras, isopach maps that have been compiled are presented and discussed. For the Cenozoic era, information on thickness of sediments in individual basins is shown on a base map and briefly analyzed in tabular form.

Five basic structures appear in Arizona on all the Paleozoic maps: two domes or positive areas (in the northeast and southwest respectively), the margins of two geosynclines (in the northwest and southeast), and a sag in central Arizona between the domes and connecting the two geosynclines. Prongs or submarine ridges extending basinward from the domes, and areas of more rapid sinking between them, appear to have shifted position from period to period.

Four major changes in isopach pattern are shown on the series of maps: (1) Northern and central

New Mexico became an area of active sedimentation starting with the Pennsylvanian; (2) central and southern Arizona became a high area contributing sediments to the north during Triassic time; (3) northern Arizona received no sediments in Lower Cretaceous time, but in southern Arizona an uplift was followed by development of a deep, northwestward-trending trough from Mexico; (4) deposits of Upper Cretaceous age were accumulated across northern Arizona in and near seas that expanded from the Rocky Mountain trough to the east.

ENGINEERING PETROGRAPHY OF LOESS

Richard C. Mielenz, William Y. Holland, and Myrle E. King
Bureau of Reclamation, Denver, Colo.

Deposits of loess in large areas of Nebraska, Kansas, and South Dakota possess adverse properties which introduce unusual engineering problems for structures founded upon them: (1) high consolidation with loading, and (2) relatively high strength when dry but low strength when wet. The dry density of the undisturbed loess rarely exceeds 90 pounds per cubic foot, and the permeability is greater vertically than horizontally.

Loess is typically grayish brown, massive, porous, and friable. Small tubes trend in all directions, but predominantly vertically; many still contain fragments of roots which formed them. Loess is composed of angular to subangular, quartzose and feldspathic silt and fine sand, each grain being surrounded by a film of montmorillonite, which binds them together at points of contact. Calcite is distributed throughout the loess largely as silt-sized granules, rather than as a cement.

When undisturbed loess is impregnated with a thermoplastic resin, thin sections reveal the structure to be open, with little interlocking of the grains. Voids occur in intergranular spaces, irregular spaces due to local consolidation on a microscopic scale, tubes related to roots, and cracks.

The low unit weight and high consolidation of loess are caused by the abundant voids, which collapse with wetting and loading. The montmorillonite binder develops a comparatively high compressive strength and shearing resistance when dry, but softens and permits easy movement of grains when wet.

Petrographic examination demonstrates that the properties of loess arise primarily from its unique structure, rather than its composition.

NICKEL-COPPER-GOLD MINERALOGY AT THE MACKINAW MINE, SNOHOMISH COUNTY, WASHINGTON*

Charles Milton
U. S. Geological Survey, Washington, D. C.

A remarkable nickel deposit, the Mackinaw Mine, Snohomish County, Washington, is one of the few known in which the nickel sulfides and arsenides are not accompanied by pyrrhotite. The ore minerals are pentlandite, maucherite, niccolite, chalcopyrite and cubanite, magnetite, vallerite, sphalerite, and gold. There are two distinct types of ore, one containing pentlandite with little or no nickel arsenides or gold, the other, nickel arsenides and gold without pentlandite (or sphalerite). In many respects the mineralogy of this deposit resembles that of the Alistos mine, Sinaloa, Mexico, described by Krieger and Hagner in 1943 and then believed to be unique.

DIRECTIONS OF OROGENIC STRESS

Peter Misch
Dept. of Geology, University of Washington, Seattle, Wash.

In asymmetric compressive structures, the "direction of movement" (horizontal component of movement of upper relative to lower portion), commonly considered as "direction from which the

* Published by permission of the Director, U. S. Geological Survey.

force has come", is merely a direction of yielding, depending on distribution of mechanically heterogeneous rock masses contending for room, and of local stresses. Yielding can be in a direction opposite to that of the most active stress. Also, alignment of direction of yielding may differ from that of strongest stresses.

Trends of individual compressive structures may change greatly within short horizontal distances, often bending at right angles. Very differently trending compressive structures in the same region are frequently contemporaneous. This suggests two-dimensional horizontal, as against linear, primary orogenic stress ("horizontal field of stress"). The same is indicated by contrasted directions of compression in different parts of strongly arcuate geosynclinal belts.

Two-dimensional horizontal primary stress becomes locally released in various directions, depending on distribution of weaker and stronger elements in heterogeneous crust. Where distribution of heterogeneous elements is pronouncedly linear (most orthogeosynclines), predominantly linear "secondary" stress operating across the weak belt results, its direction changing with the trend of the belt; weaker transverse compression is often added. Where crustal heterogeneities lack pronounced alignment, orogenic stress, as released, often maintains its original two-dimensional character.

Genetic relationships between distribution of heterogeneous crustal elements, and orogenic trends and directions of movement, emphasize importance of historic approach in structural analysis. Tectonic history of crust is one of continued two-dimensional horizontal shortening.

MESOZOIC STRATIGRAPHY OF SOUTHWESTERN MONTANA*

C. A. Moritz and L. L. Sloss
Hanover, N. H.; Northwestern University, Evanston, Ill.

The Triassic System is represented by the Dinwoody, Woodside, and Thaynes formations, all Early Triassic and largely marine. The system is widely distributed and ranges in thickness from zero in Silver Bow County to over 1500 feet in southern Beaverhead County.

The Jurassic System is represented by the marine Sawtooth, Rierdon, and Swift formations of the Middle and Upper Jurassic Ellis group, and the nonmarine Upper Jurassic Morrison formation. Jurassic strata are thin or missing in northern and northeastern Beaverhead County, thickening to several hundred feet eastward into Gallatin County and south and westward in Beaverhead County.

The Lower Cretaceous Series is represented by the nonmarine Kootenai formation. The formation is widespread, reaching thicknesses in excess of 1000 feet along the western border of its outcrop belt.

The Upper Cretaceous Series presents a complex pattern. Pyroclastics are prominent in most units of the series, and correlation with adjoining areas is difficult. The Bear River formation, the Aspen formation, and the Mesa Verde (?) formation are provisionally recognized. In addition, thick conglomerates in southwestern Beaverhead County may prove to be, at least in part, Late Cretaceous.

CAUSE OF AN ICE AGE

Frederick K. Morris
Massachusetts Institute of Technology, Cambridge, Mass.

The many theories on this subject fall into three groups that propose (1) a local uplift as initial cause of glaciation; (2) migration of the glaciated area to or near to the pole—often called "polar residence"; (3) a world-wide change of climate; most theorists propose a colder climate, but a few see the logic of a moderate increase in warmth as the cause of an ice age.

A Kenya or Cotopaxi may develop local glaciers because of altitude, but no continental glaciation was ever so caused. A test of the two remaining theories is afforded by the work of Robert W. Sayles on Bermuda. Here a dune sand corresponds to each glacial draw-down of the ocean's level, but a soil

* Published with the permission of Phillips Petroleum Company.

was formed on each dune sand when the interglacial sea rose again near to its present level. If the continents had been successively glaciated by polar residence, neither the number nor the intensity of Bermuda's alternating formations could have occurred.

The cause of the Pleistocene ice age must be world-wide change of climate. A lowering of world temperature would lessen wind strength and rainfall, giving a cool dry climate but not an ice age. A moderate increase in solar energy would increase precipitation throughout the earth.

The tropics and warm-temperate belts would develop big rivers and broad lakes, with glaciers on the highest mountains. The cool-temperate latitudes would accumulate thick ice sheets, which would die out toward the north pole because the polar area was cold and, therefore, dry.

Harlow Shapley and others have shown that passage through a nebula would increase solar radiation and might well cause an ice age.

GLACIATION IN THE SOUTHERN WIND RIVER MOUNTAINS, WYOMING

John Hall Moss
Franklin and Marshall College, Lancaster, Penna.

Mapping of Pleistocene glacial and glaciofluvial deposits along Big Sandy Creek, a tributary of the Green River, revealed a sequence of five glacial advances, the first three of which correspond to Blackwelder's Buffalo, Bull Lake, and Pinedale. During each advance a complex of morainal and outwash deposits was laid down, the latter extending more than 50 miles downstream into the adjoining Bridger Basin. The Buffalo occurs as small, formless masses of deeply weathered till about 30 miles from the cirques. The Bull Lake advance was characterized by double maxima, represented by two moderately dissected moraines 25 miles from the cirques and two extensive terraces, 60–90 and 30–50 feet above present stream grade. The Pinedale also was a compound advance as indicated by a pair of steep-fronted, little dissected moraines 10 miles from the cirques and two terraces, 15–30 and 8–12 feet above stream grade. Moraines of the fourth advance, named Temple Lake by Hack, were found not only in the Temple Lake valley, but in four other upper tributary valleys of Big Sandy as well. These partly grass-covered moraines, 60–70 feet high, consist of till stained with limonite to only half the depth of Pinedale. They are usually fronted with outwash plains continued downstream in the 4–6-foot terrace. This advance represents a significant minor swing toward a glacial climate much later than the Pinedale maxima but before the Neo-glaciation. Moraines assigned to the Neo-glaciation, the fifth advance, are composed largely of unstained angular blocks lying within 1000 feet of the small existing ice masses.

PEROVSKITE FROM CALIFORNIA

Joseph Murdoch
University of California at Los Angeles, Los Angeles, Calif.

The first California find of perovskite is from the 910 level of the Commercial quarry at Crestmore, Riverside County. The mineral occurs as brilliantly shining, deep-yellow octahedral crystals up to 1 mm. across. These are occasionally modified by small cube faces. Thin sections show the usual multiple twinning parallel to (100), and the individual lamellae are rather strongly birefringent. The perovskite is found in granular calcite, associated with numerous skeletal octahedral crystals of nearly black spinel, which is pale green in section.

PERIODICITY IN INVERTEBRATE EVOLUTION

Norman D. Newell
American Museum of Natural History, New York, N. Y.

Rates of evolution in several groups of invertebrates are estimated by means of graphs showing numbers of first appearances of genera per million years. There are from one to four peaks in each

group, representing times of rapid differentiation. These are followed by depressions, when evolutionary activity was reduced. Commonly, rates of production of genera vary with, and probably are dependent on, the total numbers of genera at a particular time. Several groups show similarity of pattern, suggesting common controls. For instance, among some groups there was a marked decline in evolutionary rates at the beginning of the Mesozoic. Some active groups, as the cephalopods and echinoids, were little affected by the crisis. Nearly all the geologic periods were marked by peaks of evolutionary activity in one or more major groups. Causes for fluctuations undoubtedly are complex, and include both biological and physical factors. Of the latter, probably the most important were the successive expansions and restrictions of shallow continental seas. These always have been the chief centers of evolution of marine invertebrates. Simultaneous emergence of all the continents would essentially eliminate a major habitat. Our evidence suggests that this happened at the close of the Permian, and probably also to a more limited degree at other times. Diastophism influences the course of evolution by causing extinctions, migrations, and modifications in habitats, but there is no evidence that there is increased evolutionary activity during diastrophic disturbances; in fact the converse may well be true.

PETROGRAPHY OF AMERICAN LIGNITES

B. C. Parks
Bureau of Mines, Pittsburgh, Penna.

The extensive deposits of low-rank coal in the United States are receiving attention as a result of declining reserves of competitively more favorable coals and development of important nonfuel uses of coal. Use of domestic lignite for solvent extraction of montan wax to replace foreign supply cut off from American industry is an example.

This paper describes occurrences of lignitic coals in the United States and includes discussion of terminology, petrographic composition, coalification, and rank classification of these coals.

Certain tests are described and data presented showing results of petrographic investigation of the source of wax and resin in lignite. Purpose of the investigation was to determine the components in lignite contributing to the solvent extraction products, and the phyteral source of "waxy", "resinous", and asphaltic elements in the extracts.

Certain varieties of attrital lignite proved to be the most important source material of waxy solvent extracts. "Pure" attrital lignite of known high solvent yield was broken down by chemical maceration which removed humic matter and freed various ingredients of the attritus, mostly yellow translucent matter. Phyteral components in the residue were spores, pollen, particles of lump-type resin, round, light and dark resinous bodies, dark "resinous" rodlets, remains of petioles, and cuticular matter.

A microscope hot stage was used to observe the effect of heat on these various ingredients and their solvent products. Information resulted which indicated that for attrital lignites tested the wax in solvent extracts is derived mainly from cuticular remains, resin from lump-type resin and round resinous bodies, and asphaltic material probably from dark "resinous" bodies. The discovery of wax associated with cuticular remains is in keeping with the fact that in living plants wax is found exclusively in cuticular coverings of leaves, petioles, and reproductive organs, and in suberin. Origin of attrital and xyloid lignites is discussed.

PRODUCTION, CLASSIFICATION, AND UTILIZATION OF WESTERN U. S. COALS

V. F. Parry
U. S. Bureau of Mines, Golden, Colo.

Western coals comprising the Rocky Mountain and Northern Great Plains provinces represent approximately 60 per cent of the estimated U. S. solid fuel reserve, but production from these fields since 1920 decreased from 7 to about 5 per cent of the national bituminous production. The reason

for decline is clear because oil and gas produced in the West has increased from the equivalent of 133 to 526 million barrels of oil in the same period. The total production of mineral fuels in the western States is now equivalent to 650 million barrels of oil, but coal supplies less than 18 per cent of this energy. The energy demand from mineral fuels will expand, but the forms of energy produced will shift as the costs vary. Without oil or natural gas, about 170 million tons of coal would be required, but coal supplied only 31 million tons in 1945. The long-range picture for coal looks bright, but the immediate demand for western coal is relatively low.

Coal is produced in 47 western mining areas, distinguished by locality and difference in quality. (Three charts of the fields are shown.) Although the average heating value of western coal is 11,400 Btu per lb (U. S. avg. = 13,500), the individual mining areas produce 6700 to 13,700 Btu coals which are predominantly noncoking with natural moisture varying up to 40 per cent. Western coals are characterized by high volatile content, and they are relatively highly reactive chemically which is favorable for manufacture of synthetic liquid fuels.

The paper includes charts showing improved methods for classifying western coals for the chemical engineer and illustrating their properties, utilization, and occurrence.

MID-PENNSYLVANIAN PELYCOSAURS FROM KANSAS

Frank E. Peabody
Department of Zoology, University of Kansas, Lawrence, Kans.

Further study of materials described in part by H. H. Land, 1945, from the Stanton formation of Anderson County discloses a partial skull and two post-cranial skeletons of the small pelycosaur, *Petrolacosaurus kansensis* Lane, originally described from a hind limb and pelvis. The genus is most closely related to primitive pelycosaurs such as the Lower Permian *Mycterosaurus*, but appears more primitive still in certain features of the teeth, palate, and tarsus. These early reptile remains are excellently preserved in marine shales containing also land plants and scorpions, marine invertebrates and coelacanth fish.

HAUCHECORNITE

M. A. Peacock
University of Toronto, Canada

A good small crystal of hauchecornite from the Friedrich mine, Hamm a.d. Sieg., Westphalia (Harvard Mineralogical Museum, 89710) is a thick square basal tablet $c(001)$ combined with the tetragonal prisms $a(010)$, $m(110)$, and the tetragonal bipyramids $q(011)$, $p(021)$, $e(111)$ ($a:c$ = 1:0.7404, goniometric and x-ray). Rotation and Weissenberg photographs around the c-axis and an a-axis show the Laue symmetry $4/mmm$, $a = 7.28$ kX, $c = 5.39$ kX ($\lambda \mathrm{Cu}K\alpha_1 = 1.5374$ kX), and the probable space group $P4_22$. With the specific gravity 6.36 measured on this crystal (17 mg.) the four existing analyses on picked material indicate the cell content $Ni_8(Bi,Sb)_8S_8$. Strongest x-ray powder lines for identification: 2.79 kX (10), 2.39 (6), 2.30 (6), 4.34 (5), 1.861 (5). Hauchecornite is thus a well-defined mineral species.

ORIGIN OF RUPTURED EOCENE COBBLES IN THE BEARPAW MOUNTAINS, MONTANA*

William T. Pecora
U. S. Geological Survey, Washington, D. C.

On the western and southern margins of the Bearpaw Mountains in north-central Montana, a conglomerate believed to be an upper member of the Wasatch formation (Eocene) and representing

* Published by permission of the Director, U. S. Geological Survey.

the close of sedimentation in the region is unconformably overlain by volcanic rocks of local origin. Many of the pebbles and cobbles in the conglomerate are fractured, crushed, bruised, gouged, or ruptured, and the displaced fragments are recemented by the matrix sand of the formation. The size, form, composition, and possible source of the material in the conglomerate are described. Various hypotheses to explain the mechanics of the rupturing are critically discussed in conjunction with geological field relations and experimental evidence.

SUBMARINE GEOLOGY: SWEDISH DEEP SEA EXPEDITION; 1947–1948

Hans Pettersson
Goteborg, Sweden

Until some ten years ago, the lack of adequate methods had more or less restricted the study of submarine geology to the very uppermost of sediments carpeting ocean floors. The thickness of that carpet was unknown. Members of the Swedish Deep Sea Expedition (ALBATROSS), July 1947–October 1948, using B. Kullenberg's "piston core sampler", took cores 10 to 15 meters in length, and located reflecting layers using W. Weibull's method for recording echoes of depth-charge explosions.

The cores taken chiefly in equatorial waters of three oceans are being analyzed in various laboratories in Sweden and abroad. Change in conditions, particularly near the counter equatorial current, are indicated by more or less pronounced stratification. Changes in level of sea bottom are also indicated in places. Considerable change in surface temperature reflecting glacial and interglacial periods are indicated by analyses of pelagic Foraminifera from the Mediterranean, Caribbean, and open Atlantic. Mediterranean cores show numerous coarse-grained layers intercalated in fine-grained sediment, largely volcanic ash, especially at levels 6 meters or more below sediment surface. Red clays of late Tertiary age from great depths in Atlantic and Pacific cannot owe their low lime content exclusively to lime-dissolving power of the ice-cold bottom waters of today.

Hard bottom, probably relatively recent lavas, inhibited coring at places in Pacific and Indian oceans. Coarse fragment layers were met in Mindanas and Romanche deeps.

Rugged bottom topography is common in all three oceans. Hummocks and distinct steps, suggesting faulting, of 50 to 100 meters are common. Flat surfaces of great extent are rare in open oceans though they are more common in the Caribbean, Mediterranean, and Sunda seas. Rugged bottom inhibited work with corers, depth charges, and trawling equipment.

Reflecting surfaces in Pacific and Indian oceans were confined to a few hundred meters below bottom, possibly because lava sheets obstructed sound waves. Considerably greater depths were reached in open Atlantic, Mediterranean, and Caribbean.

Certain lines of research are indicated: Taking and reporting of echo soundings by the Navies of the world; deeper coring; improvement in techniques for sediment sounding; measurement of thermal gradients below sediment surface; determination of radioactivity of cores; sampling of hard bottoms.

Co-ordination of research in submarine geology, as well as in other branches of deep-sea research, on an international scale is recommended.

PRE-ABO DEFORMATION IN THE SACRAMENTO MOUNTAINS, NEW MEXICO

Lloyd C. Pray
California Institute of Technology, Pasadena, Calif.

Evidence of folding and faulting prior to the deposition of the Abo formation (lower Permian) is widespread over the Sacramento Mountains, Otero County, New Mexico. Field mapping of lithologic subdivisions of the Pennsylvanian proved the regional extent of the angular unconformity at the base of the Abo. Faunal studies corroborate the field evidence.

At most places the Abo formation overlies Pennsylvanian rocks. At Arcente Canyon pre-Abo erosion stripped off about 3000 feet of sediments, mostly Pennsylvanian, and Abo is in depositional contact with beds as old as the Andrecito member of the Lake Valley formation (Mississippian-Osage).

The angular discordance is locally as high as 60°, but is generally less than 10°. The pre-Abo folds and faults trend roughly north-south. Faults dip steeply and have displacements up to about 1000 feet.

The area most affected lies several miles east of the western escarpment and extends north-south at least 28 miles in a strip up to 5 miles wide. Within this strip the deformation increases from west to east, and probably extends farther east and southeast, but is concealed by younger sediments. The unconformity may correlate with that at the base of the Hueco limestone (lower Permian) in western Texas.

The deformation and erosion must have been largely confined to the early Permian, as sediments of Virgil age are locally present below the unconformity. Some gentle folding may have continued during the deposition of the Abo sediments.

CORRELATION OF PLIOCENE OGALLALA CAPROCK CALICHE WITH REYNOSA CALICHE OF GULF COASTAL PLAIN

W. Armstrong Price
P. O. Box 1860, Corpus Christi, Texas

The theory of the origin of caliche caprocks of dissected alluvial aprons of dry regions as a soil zone with the extension by Bretz and Horberg to show the cement gotten by solution of limestone gravels permits wide correlation of the caprocks of the higher terraces, plateaus, cuestas, and divides on Pliocene alluvium and Pliocene and older rocks in all continents, looking to intercontinental correlation.

Limestone has been prominent in the coarse alluvium along the eastern flanks of the Cordillera of North America, and a high, dense, older caprock is consistently present on the larger and many smaller remnants of Pliocene alluvium from southwestern Nebraska at least to northern Vera Cruz on interior and coastal plains in semiarid to arid regions. A width of 400 and an overall length of 800 miles is indicated as a minimum.

A geographic name of early origin is suggested for this older caprock formation.

STUDIES OF OCEAN-BOTTOM STRUCTURE OFF SOUTHERN CALIFORNIA WITH EXPLOSIVE WAVES

Russell W. Raitt
University of California, Marine Physical Laboratory, San Diego, Calif.

Beginning in March 1948 seismic reflection and refraction techniques have been used to study the sediment thickness and basement velocity of the Pacific Ocean within an area between Point Eugenia in the south to Santa Cruz Island in the north and extending 800 nautical miles west of San Diego.

TNT bombs of 1 to 4 pounds for the reflection studies and ranging up to 100 pounds for the refraction studies are used as sound sources. Reflected and refracted waves are received with a pressure-actuated crystal hydrophone. Optimum results are achieved when source and receiver depths are equal to one-quarter wave length of sound of the explosion bubble pulse frequency.

In a few exceptional areas, strong echoes were observed which are believed to originate at the top of the crystalline basement beneath the sediment. However, greatest success was achieved by refraction studies.

Beyond the continental slope, in water of the order of 2000 fathoms depth, the sediment thickness was of the order of a few hundred meters, and the basement velocity was approximately 6.5 km sec^{-1}. One reversed profile of 60 km length indicates that the velocity increases to 8 km sec^{-1} at a depth of about 5 km beneath the basement surface. A strong second arrival has a velocity of 3.6 km sec^{-1} and may be a basement shear wave.

Inside the continental slope the greatest sediment thickness observed was about 3 km in Santa Cruz Basin, whose water depth is 1050 fathoms. Basement velocities range from about 4.5 km sec^{-1} near land, where metamorphic rocks outcrop, to 6.3 km sec^{-1} beneath Santa Cruz Basin.

GEOLOGICAL AND RELATED ACTIVITIES IN THE BUREAU OF RECLAMATION, JULY 1948–JULY 1949

Roger Rhoades
Bureau of Reclamation, Denver, Colo.

Geological activity increased in response to an expanding program of project investigation, design, and construction. Personnel limitations, and voluminous project work—including over 145 dams, 15 tunnels, 35 powerhouses and pumping plants, and 40 canals, to mention only major features—resulted in curtailment of research. Nonetheless some research was initiated or continued. Studies of the engineering properties of loess in foundations or used in construction was initiated to correlate physical behavior and properties with petrographic characteristics. Studies on the relation between pore characteristics of rocks and durability under freezing and thawing continued. Petrographic, X-ray, staining, and chemical investigations of clays were intensified to correlate (1) clay types with their physical behavior and engineering properties, and (2) the mineralogical and structural properties of clays with their effectiveness as pozzolans. Certain clays possess pozzolanic properties and also, for reasons related to their lattice structures, retard "alkali reaction" in concrete. Similar studies involved other pozzolans, including opaline substances and tuff and pumice.

Ground-water research was restricted to correlating results of various permeability tests using open-end and perforated casing with those obtained from Theim tests. The "stress-relief" method of measuring residual rock stress, previously developed by the Bureau, was further refined in tunnels and was used experimentally to determine stresses in a concrete dam. Triaxial shear experiments on foundation rocks continued.

Research on alkali reactivity in concrete led to further refinement of the chemical test previously devised by the Bureau for appraising reactivity of aggregates.

A simplified procedure was developed for quickly assembling peg models.

CRITICAL ENVIRONMENTS OF DEPOSITION—SHELF, SLOPE, AND BOTTOM—AND CRITERIA FOR THEIR RECOGNITION

John Lyon Rich
Geology and Geography Dept., University of Cincinnati, Cincinnati, Ohio

In any body of standing water subject to wave action there are three depositional environments—the *shelf*, the *slope*, and the *bottom*—in each of which conditions are distinctive, but within each relatively uniform. They control sedimentary facies and produce distinctive features of composition and bedding constituting criteria by which the depositional environments can be determined.

Wave base, representing the greatest depth to which the bottom is stirred by waves during storms, is a critical plane. Above it, on the *shelf*, the sediments are coarse, generally fossiliferous, rippled, cross-bedded, and show a peculiar "wavy" type of thin bedding.

The *slope*, extending from wave base down to the generally flat bottom of the water body, is a muddy environment. Fossils are few. Bedding shows a distinctive alternation of thin and remarkably even beds of clay- and silt-sized material. Flow markings, probably produced during storms by density currents, and various indications of slumping and flowage are common.

The *bottom* environment is characterized by fine material with even, uniform, and generally rather massive bedding. Paper-thin, uniform bedding may be developed close to the base of the adjoining slope.

Changes in sea level shift these environments and produce characteristic sequences of strata. One of the inferred effects of a drop in sea level is to produce, all along the outer edge of the shelf, a belt of sands capable of serving as oil and gas reservoirs. Such sand belts are likely to be misinterpreted as "shore-line trends".

STRUCTURE AND STRATIGRAPHY OF THE ANTLER PEAK QUADRANGLE, NORTH-CENTRAL NEVADA*

Ralph J. Roberts
U. S. Geological Survey, Washington, D. C.

The Antler Peak quadrangle in the Basin and Range province includes Battle Mountain. The rocks are principally upper Paleozoic sediments. They occur in two lithologic sequences, of different facies, separated by a thrust fault of Mesozoic age.

The lower-plate sequence includes six formations. Three of these—a unit of chert, argillite, and greenstone; a unit of chert, quartzite, and argillite; and a unit of sandstone, arkose, and shale—are of probable Mississippian age. They have been complexly folded and are in thrust-fault contact with each other. These units are overlain unconformably by red conglomerate, sandstone, shale, and limestone of lower Pennsylvanian age and limestone of Pennsylvanian and Permian (?) age. Quartzite, limestone, and shale of Permian (Phosphoria) age rest disconformably upon the limestone.

The upper-plate sequence includes chert, argillite, and greenstone of Pennsylvanian (?) age overlain conformably by chert, argillite, limestone, and quartzite of Wolfcamp and Leonard (?) age.

The rocks have undergone four orogenic movements, two during the Paleozoic, one during the Mesozoic, and one during late Tertiary and Quaternary time. The earliest orogeny, here named the Antler orogeny, is confined to the lower-plate sequence and took place during Mississippian (?) and early Pennsylvanian time. Major thrust faulting and complex folding of the Mississippian rocks belong to this orogeny. Later orogenic movements during the Permian were confined largely to the upper-plate sequence. Mesozoic orogenic movements that began in the Jurassic were accompanied by thrust faulting and by local folding. Normal faulting followed during the Mesozoic and the early Tertiary. The orogeny that caused the most recent uplift of Battle Mountain took place during the late Tertiary and Quaternary.

GEOLOGICAL FEATURES OF NORTH DAKOTA LIGNITES

Walter B. Roe
Truax-Traer Coal Co., Chicago, Ill.

North Dakota lignites occur in the Fort Union and upper part of the Lance formations. Individual seams range from a few inches to over 40 feet thick. The lignite horizons are quite continuous over large areas, but the individual seam representing a particular horizon is often lenticular and of limited extent horizontally.

Underclays are conspicuously absent. The lignite is woody and brown. Ash is low and sulphur conspicuously so, and moisture is high. There is indication of cyclical sedimentation.

PRELIMINARY REPORT ON THE SYSTEM LEUCITE-SiO_2-FeO

Edwin Roedder
Columbia University, New York, N. Y.

A fairly complete reconnaissance has been made of this plane through the tetrahedron representing the more general system K_2O-Al_2O_3-SiO_2-FeO. An equilibrium diagram for the condensed system (each composition including Fe_2O_3 to the amount representing equilibrium with the pure iron crucibles) is given, along with a plot of the per cent Fe_2O_3 present at the liquidus temperature. The equilibrium diagram shows that the flat liquidus surface of fayalite covers a large portion of the system, it being the primary phase even in compositions very close to the binary potash feldspar-silica eutectic. The significance of these results in the crystallization differentiation of natural magmas is discussed briefly.

* Published with the permission of the Director, U. S. Geological Survey.

PRELIMINARY REPORT ON OSTRACODA IN BOTTOM SAMPLES AND CORES OF NORTHWESTERN GULF OF MEXICO

W. Thomas Rothwell, Jr.
P. O. Box 470, Long Beach, Calif.

A Geological Society of America project grant aided in the study of ostracodes from 551 bottom samples and over 40 cores. The 12 traverses lie off the Texas and Louisiana coast and range in depth from 18 m. (60 ft.) to 3600 m. (11,841 ft.) More than 100 species were counted and graphically charted. Sets of representative specimens will be replaced at Woods Hole, the National Museum, and Louisiana State University. Restricted depth ranges delineate open-sea benthonic ostracode biozones with major boundaries as follows: Barren coastal zone, 10 m. to 24 m.; Marginal shelf biozone, 24 m.–68 m.; Upper Continental slope biozone, 68 m.–190 m.; Lower Continental slope biozone, 190 m.–1250 m.; Deep sea biozone, 1250 m.–3548+ m. Subzones reflect overlapping ranges and local environmental changes. The distribution of the major biozones is similar in all 12 traverses.

The data from some cores, however, reveal the former existence of different conditions of deposition from the present; for example, ostracodes typical of a salt-lagoon environment in a core at 37 m. depth southwest of Atchafalaya Bay are overlain by present-day open-sea forms. A core in water of 3530 m. depth on the edge of the Sigsbee deep off the mouth of the Rio Grande has early sandy sediments with lagoonal ostracodes as well as deep-sea forms. Transportation of the lagoonal ostracodes with the sand from shallow water to deep water similar to present depth is suggested.

ORIGIN OF THE EPITHERMAL MINERAL DEPOSITS

Harrison Schmitt
Silver City, N. M.

The environment during the formation of epithermal mineral deposits is likely to be duplicated in modern areas of fumaroles and hot springs. If this is assumed various implications follow: the exotic elements including the ore metals are brought in by the volcanic emanations, meteoric water plays a dominant role, the chemistry of the mineral-bearing liquids is primarily one conditioned by carbon dioxide, hydrogen sulphide, and atmospheric oxygen, the silica is mainly derived from wall-rock alterations, and the vadose circulation may be from the walls to the vein, or down and up in the vein itself as well as from the main fissures to the walls.

More general implications include: an obvious explanation for the shallow bottomings of epithermal ore shoots, the fine banding in epithermal ores, and the intricate intermingling of hypogene and supergene phenomena. Further, since the origin of the silica does not depend on a magma the postulation of the magma as the ultimate source is weakened.

FEATURES OF THE SEWARD FIRN FIELD, ST. ELIAS RANGE, CANADA

Robert P. Sharp
California Institute of Technology, Pasadena, Calif.

Seward firn field is the principal feeder of the Malaspina piedmont glacier on the south coast of Alaska. Two seasons' study of this diversified glacier system were made possible by the Office of Naval Research and the Arctic Institute of North America's "Snow Cornice" project.

Winter subfreezing temperatures penetrated 40 to 50 feet into the Seward firn in 1948–1949. This chilled layer was dissipated by 7 July, principally by meltwater percolating downward from the surface and laterally along layers in the stratified firn.

Firn densities range from 0.45–0.5 at the surface to slightly over 0.8 at 50 feet depth. Low-density layers beneath impervious ice bands indicate that density is increased by freezing of meltwater as well as by compression.

Vertical, irregularly cylindrical masses of iced firn mark channelways of downward meltwater percolation. Horizontal ice bands and lenses are thicker and more numerous near these "firn pipes". Water formed by daily thaw moves downward through isothermal firn at 6 to 8 inches per hour.

Ablation at five stations on Seward firn field averaged 0.28 inch of water per day. On Malaspina Glacier close to sea level ablation averaged 2.4 inches of water per day. The budget year, 1948–1949, was prosperous for the Seward-Malaspina system as excess accumulation on Seward firn field was 67.5 inches of water compared to 23.5 inches in 1947–1948 and 17.5 in 1946–1947.

Preliminary results from seismic and gravity surveys indicate these methods are suitably complementary in determining depth and configuration of the subglacial rock floor.

SUBMARINE GEOLOGY INVESTIGATIONS AT SCRIPPS INSTITUTION OF OCEANOGRAPHY (EXHIBIT)

Francis P. Shepard
Scripps Institution of Oceanography, La Jolla, Calif.

Expansion in the field of submarine geology at Scripps Institution has been made possible through funds from the Office of Naval Research, the Bureau of Ships, and the Beach Erosion Board of the Army Engineers. Some unpublished results of research carried out in various branches of this field by members of the staff and graduate students are exhibited. This includes the following:

1. Maps and core samples illustrating the character and distribution of sand layers found in the deep water muds of San Diego Trough—Ludwick.
2. Graph showing a displaced shallow Foraminifera faunal zone as evidence for slumping in San Diego Trough—Phleger.
3. Profiles illustrating recent slumping in La Jolla submarine canyons—Shepard.
4. Submarine topography and sedimentation distribution off La Jolla with range grid system of locations—Shepard, Sayner, and Inman.
5. Mugu submarine canyon, topography, sedimentation, and beach changes—Inman.
6. Block diagram illustrating land and sea relation of canyon at Carmel—Sayner.
7. Diagram illustrating sedimentation conditions on the shelf in the Santa Barbara area—Thompson.
8. Contours of continental slope of northwestern Gulf of Mexico—Treadwell.
9. Graphs illustrating seismic studies of the structure of the ocean bottom off southern California—Raitt (Marine Physical Laboratory).
10. Variable field electromagnetic mineral separator with graphs illustrating its application to sediment studies—Frautschy.
11. Diagrams and photos of a multisock sediment trap—Inman.
12. Diagrams of near-shore circulation at La Jolla and near-by areas—Inman and Quinn.
13. Graphs illustrating variation of longshore bars and troughs with waves and currents—Shepard.
14. Orbital current meter with records indicating nature of currents accompanying wave motion—Inman.

PERIODICITY IN VERTEBRATE EVOLUTION

George Gaylord Simpson
American Museum of Natural History, New York, N. Y.

Graphs are presented showing rates of known origin ("first appearances per million years") of orders, families, and genera in each of seven classes of vertebrates (omitting birds) for each period of their history from Ordovician to Tertiary. One, two, or three peaks occur in each class when these rates reached a high, and after which they declined, usually sharply. Peaks in rate of origin of orders regu-

largly precede those for genera by some 25 to 50 million years. A similar span intervenes between the first appearance of each new major adaptive type or structural grade and the ordinal peak that regularly follows such an event. Altogether, the sequence suggests a cycle in a continuous process. Episodes of "explosive evolution" cannot be defined as limited to or caused at any particular point in the process, and therefore periodic diastrophic episodes in the earth's crust cannot be shown to have a causal relationship to them. Classes and other major groups do not demonstrably tend to arise at or immediately after period boundaries or the tectonic episodes commonly supposed to define these. The real periodicity that does appear in vertebrate history seems to result from orderly evolutionary progression, succession, and replacement rather than being conditioned primarily by any periodic physical phenomena. Physical events in earth history are among the complex factors which, all together, produce and guide evolutionary change. No support is found, however, for the theory of simultaneous, world-wide physical and biological climaxes or crises at the period and era boundaries.

PALEOZOIC STRATIGRAPHY OF SOUTHWESTERN MONTANA*

L. L. Sloss and C. A. Moritz
Northwestern University, Evanston, Ill.; Hanover, N. H.

Within the area all Paleozoic systems except the Silurian are represented. Cambrian strata are similar to those of better-known areas to the north and east, but differ in the presence of several intrasystemic unconformities. The Ordovician Kinnikinic quartzite occurs along the Idaho-Montana border, whereas a thin edge of Bighorn dolomite is found in Gallatin County. Elsewhere, Cambrian strata are overlain by Upper Devonian.

Devonian strata of the Jefferson and Three Forks formations are typically developed and widespread, with little lateral variation. The Mississippian System, on the other hand, is characterized by extremes of facies expression, including red beds, evaporites, fragmental limestones and dolomites, and carbonaceous shales. Mississippian rocks range from 1000 to over 4000 feet in thickness.

Pennsylvanian strata are dominated by the quartzose and well-cemented sandstones of the Quadrant formation, which ranges in thickness from approximately 100 feet to nearly 3000 feet. The Permian System is represented by the Phosphoria formation, composed of quartzites, limestones, dolomites, black shales, phosphorites, and bedded cherts.

DUNE FORMS IN WESTERN NEBRASKA

H. T. U. Smith
Geology Dept., University of Kansas, Lawrence, Kans.

Sand hills, or stabilized dunes, occupy approximately 20,000 square miles in western Nebraska, or roughly one quarter of the area of the State. The dunes fall into three main groups: (1) an older group of major dune ridges ranging up to several miles in length and more than half a mile in breadth; these dunes generally trend E.-W. to E.-NE., but locally swing farther to the NE. and SE.; (2) an intermediate group of shorter, much narrower, closely spaced dune ridges trending in general E.-SE., and at many places transecting the older dunes; and (3) a comparatively young group of blowouts and minor irregular forms which occur both superimposed on all older dunes and in places where no antecedent dune forms are recognizable. The areal distribution of the above groups of dunes is mapped, and their relation to geologic history and drainage development is discussed.

* Published with permission of Phillips Petroleum Company.

CONGLOMERATES OF WESTERN TRANS-PECOS TEXAS AND THEIR RELATION TO A TECTONIC BOUNDARY*

J. Fred Smith, Jr., and Claude C. Albritton, Jr.
Geological Survey, Geol. Div., Denver Federal Center, Denver, Colo.; 3436 University Blvd., Dallas, Texas

The Diablo Plateau area in the Basin and Range province has remained a persistent platform over which formations of relatively uniform thickness have been deposited, whereas the Sierra Madre Province has been an active area of downwarping, deposition of thick wedging sediments, and intense deformation. Conglomerates of limestone and other chemically unstable rocks, notable for their presence throughout the stratigraphic section, attest repeated diastrophism along the border zone between the provinces.

In the Van Horn region P. B. King has mapped a Precambrian formation consisting of a thick sequence of limestone conglomerate; an overlying formation of Precambrian or Cambrian age contains numerous beds of conglomerate composed of granite and rhyolite pebbles. In the Sierra Blanca region to the west some exposures of rocks of Permian age contain about 25 per cent limestone conglomerate; the lower part of the formation of Jurassic age contains approximately 12 per cent limestone conglomerate; and the lowest exposed formation of Cretaceous age in the southeast part of the region contains 5 per cent limestone conglomerate.

In the Diablo Plateau region the strata are almost flat-lying or lie in broad gentle flexures and are broken by normal faults. In the Sierra Madre province the strata are folded and broken by large thrust faults; at least three major thrusts are recognizable in Hudspeth County.

GEOLOGY OF THE IRWIN DISTRICT OF COLORADO

Arthur A. Socolow
Dept. of Geology, Southern Methodist University, Dallas, Texas

The Irwin district, west of Crested Butte, in Gunnison County, Colorado, is an area of geologic interest that goes beyond the local coal and silver deposits. The region has had a complex structural, stratigraphic, and intrusive history.

Through a thick series of sediments have come up a number of intrusives ranging from tremendous laccoliths to swarms of dikes and sills.

This paper deals with some of the findings relating to the emplacement of the various igneous bodies. The deuteric effects, the structural deformation, the related hydrothermal deposits, and the hydrothermal alteration are discussed.

Intense epidotization of the sediments is a result of hydrothermal activity, but intensity is a function of type of igneous body, distance from contact, and distance from the sources of the igneous material.

Intrusion of the igneous material was apparently responsible for intense faulting and some folding. The faults became favorable loci of deposition of hydrothermal solutions which represented the end stages of igneous activity. The rich veins of arsenopyrite, native silver, gold, and ruby silver have made the area famous. The hydrothermal alteration of the igneous and sedimentary rocks is intense.

NEW CEBOID MONKEYS FROM THE LA VENTA LATE MIOCENE OF COLOMBIA, SOUTH AMERICA

R. A. Stirton
University of California, Berkeley, Calif.

A new species of the Miocene genus *Homunculus* and two other new genera of ceboid monkeys are described from the La Ventra fauna (late Miocene) of Colombia, South America. One of the new

* Published by permission of the Director, U. S. Geological Survey.

genera is most closely related to the genus *Pithecia* but is more progressive in size reduction in the posterior molars and in certain other features in the skull and dentition; an incomplete skeleton is described. The other genus is based on a mandible, not distantly related to the marmosets, but it retains three molars. Ameghino's genus *Homunculus* is represented by part of a mandible and an isolated lower molar.

It is hypothesized that the Cebidae arose from one of the Paleocene prosimian stocks of Holarctica and perhaps experienced most of their evolution in Central America before they finally reached South America in early Miocene time by rafting across a water barrier.

DACITES FROM LAUGHLIN PEAK, COLFAX COUNTY, NEW MEXICO

Helen Stobbe
Dept. of Geology, Smith College, Northampton, Mass.

Laughlin Peak, one of seven eroded volcanic cones of dacite in northeastern Colfax County, New Mexico, is located 11 miles north of Chico. In a previous paper the writer described specimens from this cone as vitrophyres, because of the large proportion of glass and lack of chemical data. Study of additional specimens and a chemical analysis show that the rocks from Laughlin Peak, the northeast side and top, are similar to dacites on the other cones.

Hand specimens are pale gray or gray and pink-banded, fine-grained, and vesicular. Micrometric analyses range as follows: Glass 83–65 per cent, plagioclase 21–12 per cent, hornblende 8–1 per cent, magnetite 14–2 per cent. The average mode of seven slides is glass 73 per cent, plagioclase 16 per cent, hornblende 3 per cent, magnetite 7 per cent. The feldspar is oligoclase (Ab_7An_3); hornblende is usually the basaltic variety.

The norm (in part) calculated from the chemical analysis follows: Quartz 26 per cent, orthoclase 15 per cent, albite 36 per cent, and anorthite 12 per cent. Orthoclase slightly exceeds anorthite. Therefore the rock is close to the border between rhyolites and dacites, and could be called a soda rhyolite or rhyodacite. The chemical analysis and norm are similar to those from Red Mountain and Cunningham Butte.

There is no marked chemical difference between these rocks. Although Laughlin Peak specimens are less crystallized, they do not differ mineralogically from the dacites of the other cones—Towndrow Peak and Red (or Bell) Mountain, both on Johnson Mesa, Cunningham Butte, Green Mountain, Raspberry Peak and Palo Blanco—the large cone 8 miles southeast of Laughlin Peak.

SEQUENCE OF CAMBRIAN TRILOBITE FAUNAS IN SOUTHEASTERN ARIZONA

Alexander Stoyanow
University of Arizona, Tucson, Arizona

Stratigraphic succession of Cambrian trilobites in southeastern Arizona admits of the following zonal units (in ascending order): (1) *Kootenia, Agraulos* and affiliated genera, *Glyphaspis, Ehmania, Etrathiella, Eldoradia, Olenoides,* (Santa Catalina formation, Cochise formation); (2) *Tricrepicephalus, Arapahoia* (*Hesperaspis*), *Blountia* (Abrigo formation); (3) *Aphelaspis, Camaraspis* (Rincon limestone); (4) *Elvinia, Iddingsia, Pterocephalina* (Peppersauce Canyon sandstone); (5) *Idahoia, Maladia, Chariocephalus, Drumaspis* (Copper Queen limestone).

As yet there is no evidence in southeastern Arizona of the older *Glossopleura-Alokistocare* fauna, so well represented in Sonora (Arrojos formation) and in the Grand Canyon area (Bright Angel shale). The paper contains a detailed description of standard and new species, distribution and interrelation of the formations, and a paleogeographic outline. Representative specimens of the above genera will be shown by lantern slides.

NONTRONITE AT BINGHAM, UTAH

Bronson Stringham and Allen O. Taylor
University of Utah, Salt Lake City, Utah

Nontronite has been found in abundance on the upper southwest levels of the Kennecott Copper Mine at Bingham, Utah. The rocks in this area were originally arkosic quartzites with dolomitic and/or argillaceous impurities. Contact action in these rocks has developed interstitial diopside, tremolite, and pyrophyllite. Nontronite is present in localized areas as a weathering product of these minerals and orthoclase, where pyrite was present to supply iron for its development. Chemical analysis shows the mineral to have the formula

$$(Al_{.59}Fe_{1.62}Mg_{.31})\ (Al_{.82}Si_{3.48})\ O_{10}\ (OH)_2 \times .38.$$

Differential thermal curves show a double endothermic peak between 600° and 700°C. as would be expected of a low-iron nontronite.

MAP OF EOLIAN DEPOSITS IN NORTH AMERICA

James Thorp and H. T. U. Smith
Division of Soil Survey, University of Nebraska, Lincoln, Nebr.; Dept. of Geology, University of Kansas, Lawrence, Kans.

In August 1948 the Division of Geology and Geography of the National Research Council appointed a committee to prepare a map of eolian deposits in North America north of Mexico. The purpose is to bring together on one sheet all available published and unpublished data on eolian sand, loess, and eolian clay deposits. It is hoped that this will reveal relationships significant to the geomorphologist and Pleistocene geologist, provide stimulus and aid to the soil scientist in the study of soil genesis, and guide future research in eolian geology and soil science.

The scale planned for publication is 1:5,000,000. Within the limitations of this scale, it is proposed to differentiate Loveland and Wisconsin loess and to subdivide the latter where feasible. Where adequate data are available, thickness of loess will be shown by isopachs. In mapping dune sand, morphology and orientation of dune forms, and active or stabilized condition of the sand will be shown where possible. The final map will be accompanied by an explanatory text with bibliography.

The committee consists of eight American and two Canadian members, of whom five are geologists and five are soil scientists. Seventy-five to one hundred other scientists have collaborated with the committee to date. Following are members: Mark Baldwin, W. E. Bowser, Richard Foster Flint Lawrence M. Gould, H. C. Moss, E. C. Reed, Guy D. Smith, A. C. Trowbridge; H. T. U. Smith and James Thorp, Co-Chairmen.

A preliminary draft of the map is exhibited. In order that the final compilation may have maximum accuracy and usefulness, criticisms, suggestions, and additional data are earnestly solicited.

NUCLEAR RADIATIONS IN WELL LOGGING

Charles W. Tittle, Clark Goodman, and Henry Faul
North Texas State College, Denton, Texas; Massachusetts Institute of Technology, Cambridge, Mass.; U. S. Geological Survey, Washington, D. C.

The ability of neutrons and gamma rays to penetrate a few feet of solid materials has been applied during the past decade as an empirical index of subsurface structure and composition surrounding cased-drill holes. Geiger counters and pressurized ionization chambers have been used to detect gamma rays emitted by radioactive elements in the formations. Similar probes detect gamma rays emitted when neutrons from a portable source are captured in surrounding materials. To date these logging techniques have received limited treatment in the literature. Hence the applications and limitations are defined largely by experience rather than understanding.

Accordingly, studies are being made in this laboratory of (1) slowing-down and diffusion of neutrons, (2) production and absorption of gamma rays from inelastic scattering and radiative capture of neutrons, and (3) distribution and absorption of neutrons and of gamma rays under conditions that simulate field operations. Although this work is still in the initial stages, certain conclusions are appearing: (1) the possibilities and limitations of present logging techniques can be established; (2) by improvements in present operating procedures increased knowledge of subsurface conditions should result; (3) neutron flux measurements should provide additional information of practical value; (4) such measurements, when made simultaneously at several points along the axis of the drill hole in the vicinity of a porous formation, can, under favorable conditions, distinguish between oil (and/or fresh water) and salt water; and (5) there is considerable room for theoretical work concerning the interactions of gamma rays and neutrons with terrestrial materials, well fluids, and casing.

SUBMARINE TOPOGRAPHY IN THE NORTH ATLANTIC

Ivan Tolstoy
Columbia University, New York, N. Y.

In the North Atlantic one may distinguish several distinct types of topography, each of which is characteristic of certain portions of the ocean floor.

The continental slopes are now known to show in many cases a steplike succession of horizontal or imperceptibly sloping shelves or terraces. They are dissected by systems of submarine canyons, the pattern of which is such as to suggest to many a subaerial origin. A recent investigation of the Hudson submarine valley by the ATLANTIS has show that this valley extends at least as far as the 2200-fathom curve, 300 miles out to sea, and shows features suggesting a subaerial origin.

The broad basins are characterized by smooth floors or plains covering areas of more than 100,000 square miles out of which there rise large sea mounts, isolated or in groups. Thus plains at a depth of 2900 fathoms occupy the floors of the North American and the North Canary basins.

The floor of the northwestern part of the North American basin, north of Bermuda, is characterized by a plain at 2650 fathoms. Sea mounts of various sizes and shapes rise out of these otherwise smooth plains. There is a conspicuous group of flat-topped sea mounts rising from the 2650-fathom plain of the western North American basin. They rise approximately to 800 fathoms and string out toward the southeast, roughly from the direction of Cape Cod. They show evidence of terracing on their flanks.

The central part of the Atlantic Ocean is characterized by a long submarine mountain range, extending from Iceland to a point southwest of the Cape of Good Hope, known as the Mid-Atlantic Ridge. Numerous fathograms across the Ridge have shown that it is characterized by a high central zone, or Main Range, consisting of parallel ridges following the general trend of the Ridge and rising in many places to less than 800 fathoms below the surface of the ocean.

Between 1600 and 2500 fathoms the flanks of the Ridge are characterized by a succession of flats which for the lack of any better term have been called terraces. Reflection-shooting studies by Ewing and Press and others have shown that these terraces are or have been areas of greater deposition.

Finally, between this Terraced Zone and the 2900-fathom plain, one may usually recognize a mountainous area standing out as a distinct physiographic province.

ASSIMILATION (?) OF MICACEOUS SCHIST BY DIABASE

W. Harold Tomlinson
260 N. Rolling Rd., Springfield, Penna.

The author found inclusions of highly altered micaceous schist in diabase in the Umble Farm Quarry at Safe Harbor, Pennsylvania. Rising through the magma these inclusions left a tubular trail. In cross section they show, megascopically, a rounded contour and are surrounded by a zone of hybrid rock of fairly uniform composition which sharply separates the inclusions from the diabase. There is

a close resemblance between this hybrid rock and some abnormal phases of the diabase formation exposed at other localities.

Mineral and chemical composition of the inclusions, the hybrid rock and the diabase are given. No conclusions seem warranted, but the occurrence suggests a possible origin for certain phases of the diabase intrusive.

CRYSTAL STRUCTURE OF BORNITE FROM ILLOGAN, CORNWALL

G. Tunell and C. E. Adams
Dept. of Geology, University of California, Los Angeles, Calif.

A rotation photograph and a set of equi-inclination Weissenberg photographs were made of a single crystal of bornite from the Carn Brea Mine, Illogan, Cornwall, using filtered cobalt radiation. Although the three crystal axes are equal in length within the error of our determination, and the three interaxial angles are 90°, the structure is not truly cubic. The unit cell is pseudo-cubic with a_o = 32.8 Å. The structure is approximated by the following arrangement in a cubic cell with a_o^1 = 5.47 A (= $\frac{1}{6} \times 32.8$Å): four copper or iron atoms distributed statistically over the four positions $\frac{111}{444}$, $\frac{331}{444}$, $\frac{133}{444}$, $\frac{313}{444}$, two copper or iron atoms distributed statistically over the four positions $\frac{131}{444}$, $\frac{311}{444}$, $\frac{113}{444}$, $\frac{333}{444}$, the total number of copper atoms in this cell being five and the total number of iron atoms being one on the average; four sulphur atoms on the positions 000, $\frac{11}{22}0$, $0\frac{11}{22}$, $\frac{1}{2}0\frac{1}{2}$. This approximate structure yields calculated intensities for all the strong and medium spots in good agreement with those observed; it yields small or zero calculated intensities for all the weak spots. The weak spots for which the calculated intensities are zero prove that the structure is actually more complicated, but the nature of the deviations from the approximate arrangement has not been found in our work.

HIGH-TEMPERATURE ALBITE

O. F. Tuttle and N. L. Bowen
Geophysical Laboratory, Washington, D. C.

Synthetic albite has optical and x-ray properties notably different from natural albite of granites and pegmatites, but like those of albite from some volcanic rocks. On prolonged heating at high temperature pegmatitic albite inverts to a modification identical with the synthetic material. In the presence of fluxes the change takes place as low as 700°C. Albite twinning is observed in both forms.

FORMER MARINE SHORE LINES OF THE GAVIOTA QUADRANGLE, SANTA BARBARA COUNTY, CALIFORNIA

Joseph E. Upson
Geological Survey, Ground Water Branch, 1330 J St., Sacramento, Calif.

In the Gaviota quadrangle, along the west-trending portion of the southern California coast, at least 18 or 19 former marine shore lines are recognized. Below an altitude of 200 feet they are indicated by characteristic erosional and depositional features. Shore line altitudes are at approximately 5, 25, 40, 60, 90, 125, and 180–200 feet. They are not noticeably deformed. Development of the 25-foot, and possibly 90-foot, shore line was preceded by a period of stream down-cutting possibly induced by temporarily lowered sea level. Marine shells from deposits on the platforms associated with the 60-foot and 90-foot shore lines, identified by W. P. Woodring, are not inconsistent with a late Pleistocene age. Above 200 feet, benches, flattish ridge crests, and hill summits at a series of accordant elevations are considered remnants of marine terraces. The corresponding shore lines are at roughly 275, 360, 470, 560, 620, 720, 825, possibly 950, 1060, 1200, 1260, and 1390 feet, and possibly higher, above present sea level.

The altitudes of shore lines below 200 feet agree closely with those described for the southeastern Atlantic Coast and certain Pacific islands. Thus, they suggest world-wide positions of sea level, possibly glacial, although inferred episodes of lowered sea level do not entirely coincide. The shore lines above 200 feet presumably were formed during and after the southern California supposed mid-Pleistocene deformation. However, if the lower shore lines occupy most of the glacial period, the higher shore lines are largely pre-glacial—an interpretation that conflicts with mid-Pleistocene age for the deformation.

MELONITE FROM BOULDER COUNTY, COLORADO

Ernest E. Wahlstrom
Dept. of Geology, University of Colorado, Boulder, Colo.

Polished-section and X-ray studies of the telluride ores of Boulder County, Colorado, establish that melonite ($NiTe_2$) in small amounts is widespread and is an early mineral in a complex epithermal sequence including a variety of sulfides, tellurides, and gangue minerals.

PROBABLE ILLINOIAN AGE OF PART OF THE MISSOURI RIVER*

Charles R. Warren
Dept. of Geology, Washington and Lee University, Lexington, Va.

Eleven miles south of Chamberlain, S. D., gravel brought from the west by the White River occurs on the east bank of the Missouri River and perched 550 feet above it. C. Bertrand Schultz considers vertebrate fossils from this gravel to be late Kansan or early Yarmouth.

Just north of the hill capped by this gravel lies an old valley of the White River, now largely filled with till. A cross section of the till-filled valley exposed in the east wall of the Missouri Trench shows that the White River cut down more than 400 feet, widening its valley in the process, after it had deposited the high fossiliferous gravel and before glacier ice dammed its lower course and forced its diversion to form the Missouri. Thus, if Schultz's dating of the high gravel is correct, the glacier ice that caused the diversion was of a post-Kansan stage, either Illinoian or Wisconsin.

Several lines of evidence suggest that the diversion took place prior to the Wisconsin. It is therefore believed probable that the glacier ice that diverted the White River, creating at least the Chamberlain portion of the Missouri, was Illinoian. Although no evidence of Illinoian glaciation had previously been recognized west of eastern Minnesota, it appears likely that Illinoian glacier ice may have had considerable importance in the geomorphic history of the Dakotas.

WAX AND WANE OF SPECIES IN PALEOZOIC OSTRACODA

A. Scott Warthin
Vassar College, Poughkeepsie, N. Y.

Diagrams of species abundance for selected genera of Paleozoic ostracodes indicate that periods of rapid speciation occurred in the Lower and Upper Silurian, the Middle Devonian, and from Upper Mississippian through Middle Pennsylvanian time. Notable wanings of species occurred at the end of the Silurian, the beginning of the Upper Devonian, and presumably in Permian time. These changes in abundance are related to minor and relatively local changes in environment, rather than to widespread diastrophism.

* Published by permission of the Director, U. S. Geological Survey.

EFFECT OF POTASSIUM ON THE NEPHELINE-CARNEGIEITE TRANSFORMATION

Edward Washken and M. J. Buerger
Geology Dept., Massachusetts Institute of Technology, Cambridge, Mass.

When the temperature of a melt of composition $NaAlSiO_4$ is lowered through its freezing point, crystals of carnegieite form. Carnegieite transforms sluggishly into nepheline at 1248°C. If one wishes to obtain nepheline directly from a melt this may be done by reducing the freezing point of the melt below this transformation point by the addition of a flux like lithium fluoride. Obtaining single crystals of nepheline by this method involves certain difficulties.

Recent crystal-structure studies show that the composition $NaAlSiO_4$, while natural to carnegieite, is foreign to nepheline, and indeed is clearly forced on the crystals of nepheline by the above method of production. Normal nepheline requires one alkali atom in four to be potassium. In confirmation of this finding, naturally occurring nepheline has a composition tending toward $KNa_3Al_4Si_4O_{16}$. Since the K atom is large for the available alkali sites in the carnegieite structure the composition $KNa_3Al_4Si_4O_{16}$ is foreign to carnegieite. It would appear possible to avoid the formation of carnegieite by cooling a melt of that composition.

Crystallization experiments show this line of reasoning to be correct. The x-ray powder pattern of the product obtained by cooling a melt of the composition $KNa_3Al_4Si_4O_{16}$ agrees with the pattern of natural nepheline.

This work was carried on in the Washken Laboratories, Cambridge, Massachusetts, under a development contract with the Squier Signal Laboratory, U. S. Army Signal Corps, Fort Monmouth, New Jersey.

ENSIMATIC AND ENSIALIC GEOSYNCLINES*

Francis G. Wells
P. O. Box 536, Grants Pass, Oregon

Deposits in geosynclinal prisms are of two types: (1) sediments derived from the weathering of the crust and deposited on a downsinking floor of sial, the classical geosyncline; and (2) effusive rocks and accumulates on a sima floor.

Deposits of (1) consist of argillaceous rocks, quartz sandstones, widespread limestones and dolomites, arkoses, conglomerates, and terrestrial deposits. Open and alpine types of folding and overthrusting predominate, and the igneous rocks are of the Atlantic type.

Deposits of (2) consist of spilitized basaltic flows and pyroclastics overlain by andesitic and dacitic pyroclastics and flows. Shales and mudstones composed of volcanic dust and ash, with little quartz and primary kaolin, are intercalated with the more silicic effusives. These grade into sandy graywacke also composed of volcanic debris and containing little if any quartz. Limestones, except for small reefs, are absent. Chert lentils are associated with graywackes. No terrestrial deposits are present. From top to bottom the deposits are almost entirely volcanic and show no traces of chemical weathering. Isoclinal folding and high-angle reverse faulting rule. Peridotites are characteristic, and the other intrusive rocks are of the Pacific type. Palingenesis is common.

The terms ensialic and ensimatic geosynclines are proposed to designate these distinctly different types. The sialic crust has been built up of increments of ensimatic geosynclines. Complete sections through ensimatic geosynclines are exposed only in Precambrian shields, the Keewatin of Canada being a good example, but what are believed to be younger ensimatic geosynclines are found around the peripheries of the sima basin of the Pacific, and the rocks younger than the Chico formation of the northern Klamath Mountains probably are in a younger ensimatic geosyncline.

* Published with the permission of the Director, U. S. Geological Survey.

EAST-WEST CROSS SECTION THROUGH THE SOUTHERN PERMIAN BASIN OF WEST TEXAS

West Texas Geological Society Stratigraphic Committee
Midland, Texas

A cross section has been constructed through the southern Permian Basin of West Texas, extending from Fisher County on the east through El Paso County on the west, an airline distance of 360 miles. This location is somewhat farther west and generally slightly farther north than that of the section by the West Texas Geological Society published in April 1942.

Deep drilling since that time has brought out a large amount of new information on the older beds, so that the section is drawn down to or close to the Precambrian over the greater part of its length. To facilitate comparison with the 1942 cross section the same original scale of 1000 feet to the inch vertically and 2 miles to the inch horizontally has been used, and colors illustrate the various types of rocks. In addition, minor lithologic constituents have been shown by symbols. This extra detail has made possible the use of more stratigraphic names, including some which have never been described in the literature but are in daily use in the petroleum industry.

Fifty-one wells are labeled, and innumerable others were used during the work. Most of them are deep pre-Permian tests drilled since the 1942 section was published.

The text accompanying the cross section is intended mainly as an explanation of it rather than a résumé of the geology of all West Texas.

PERMIAN-MESOZOIC STRATIGRAPHY IN NORTHEASTERN NEVADA

Harry E. Wheeler, W. Frank Scott, and Thomas L. Thompson
Univ. of Washington, Seattle, Wash.; University of Washington, Seattle, Wash.; Boulder, Colo.

Near U. S. Highway 93 between Currie and Spruce Mountain, southeastern Elko County, Nevada, the marine Permian sequence includes dolomites and limestones of undetermined thickness belonging to the upper part of the Oquirrh formation, together with approximately 1600 feet of limestones, dolomites, cherts, phosphorites, and detrital clastics, containing a typical Phosphoria (Guadalupian) fauna. Elements characteristic of the Phosphoria, Park City, Gerster, and Kaibab formations are present in this unit.

More than 3100 feet of Triassic strata (limestones, siltstones, sandstones, and conglomerates), with the *Meekoceras* zone near their base, disconformably overlies the Permian. From the base upward this sequence contains units lithologically similar to the Woodside, Thaynes, Moenkopi, Shinarump, and Chinle formations. These rocks have an over-all similarity to the Harrington formation of the San Francisco district, Utah.

The Chinle-like beds appear to grade upward into more than 2000 feet of red, buff, and white, cross-bedded, Jurassic(?) sandstones which closely resemble the Nugget and Glen Canyon.

This Permian-Mesozoic section, measuring in excess of 6700 feet, with its close stratgraphic affinities to the Colorado Plateau and Rocky Mountain regions, proves the continuity of Permian and Early Triassic seas across Utah into northeastern Nevada. The prevalence of widespread, marine and continental, shelf environments, during most of the interval from Late Permian to Early Jurassic(?), is recognized as extending well beyond previously regarded distribution limits. Permian phosphorites are recognized for the first time in Nevada, approximately 160 miles west of their previously known occurrence in the Wasatch Range, Utah.

DIVERSE CONCEPTS OF THE AMSDEN FORMATION*

James Steele Williams
U. S. Geological Survey, Washington, D. C.

Darton defined the Amsden formation in 1904 as a "variable succession of red shales, limestones, cherty and sandy members", between the Little Horn (name now replaced by Madison) limestone and

* Published by permission of the Director, U. S. Geological Survey.

the sandstones of the Tensleep. The formation is a good map unit because of its distinctive nonresistant character and topographic expression. It contains Pennsylvanian fossils in its upper part, and fossils thought to be Mississippian have been found near its base near the type locality. The formation was widely recognized in Wyoming by many geologists in the sense in which Darton proposed it, and, as so used, it contains fossils definitely of Mississippian age in its lower part in some areas. In other places it may be entirely Pennsylvanian.

More recently efforts have been made to restrict the Amsden to that part of the formation thought to be Pennsylvanian and to extend it beyond Wyoming into Montana and Idaho as a Pennsylvanian formation. In some areas this has resulted in rock units that are not readily mappable on scales commonly used. In others it has meant that the mapping of the formation was based on recognition of key beds or fossil zones rather than on the original concept of total lithology and topographic expression. Unconformities occur at several stratigraphic zones. Fossils are scarce at many localities, and diagnostic faunules have not been obtained from critical beds.

A local name might well be substituted for the beds called Amsden in those parts of Montana where the name has been extended but restricted to rocks of Pennsylvanian age that represent only a part of the widely held lithologic concept of the formation. Where units within the sequence are mappable as formations, the Amsden could be raised to group status. No reason appears to the writer to prevent a valid formation like the Amsden from crossing epoch (or even period) lines, from being mostly Mississippian in one area but Pennsylvanian in another, or from embodying parts of both Mississippian and Pennsylvanian epochs in any single area.

STRUCTURE IN ARIZONA

Eldred D. Wilson
Arizona Bureau of Mines, University of Arizona, Tucson, Ariz.

The map data presented indicate that much remains to be learned regarding Arizona structure, and for large areas age relations are indeterminate.

All the principal deformations recognized—older Precambrian (Mazatzal), younger Precambrian (Grand Canyon), Nevadian, Laramide, and late Cenozoic—were characterized by lateral compression, igneous activity, and normal faulting; they differ mainly in the relative intensity of these effects as exposed. For the Mazatzal, Nevadian, and Laramide, the folding, reverse faulting, and batholithic invasions predominate over normal faulting. For the younger Precambrian and late Cenozoic, regional uplift, volcanic activity, and normal faulting overshadow the broad flexing, local sharp folding, and known thrust faulting.

Compressive forces during Precambrian seem in general to have acted from the southeast and east whereas those of the later deformations acted from the southwest and west, toward the Plateau area. Evidently the Precambrian structures influenced subsequent tectonic developments.

Correlations with McKee's isopachs are suggested.

The Nevadian disturbance was strong in southeastern Arizona and probably also in western Arizona, although apparently mild in the Plateau area.

Effects of the Laramide revolution were most intense in the Basin and Range province and appear chiefly as open folds in the Plateau area.

Uplifts during later Cenozoic are reflected in present topography. The normal faults were superimposed upon, and are believed to be largely inheritances from, earlier structures. Some, at least of the tilted block mountains probably represent faulted segments of folds.

Possible application of the strain ellipsoid is discussed.

STRATIGRAPHY AND FAUNAL RELATIONSHIPS OF THE UPPER CAMBRIAN IN THE CENTRAL APPALACHIANS

James Lee Wilson
2207 Del Monte Dr., Houston, Texas

This paper presents results of a stratigraphic and paleontologic study of the Upper Cambrian exposed in two linear belts in the Central Appalachians: (1) in the Nittany Arch region of southern

Pennsylvania (Warrior and Gatesburg formations), and (2) in the Shenandoah-Cumberland Valley of Virginia, West Virginia, Maryland, and Pennsylvania (Elbrook and Conococheague formations). Cambrian stratigraphy in the two areas is refined, a new member being named in the lower Conococheague limestone. A general facies change west to east from arenaceous dolomite (Gatesburg formation) to silt-laminated limestone (Conococheague formation) is indicated in the geosyncline.

Charles Butts' earlier correlation of the Warrior with the Elbrook and the Gatesburg with the Conococheague formation is found to be approximately though not precisely correct on the basis of trilobite faunas. The paleogeographic significance of the stratigraphy is outlined on a regional isopachous-facies map.

Trilobites identified from the Warrior, upper Elbrook, and lowest Conococheague formations indicate a Dresbachian age for these beds. Trilobites of Franconian age from the middle Gatesburg and lower Conococheague formations show more complex relationships. The Ore Hill member of the Gatesburg formation is demonstrated to contain in descending order the *Conaspis* and *Elvinia* faunizones, the latter of which is replaced to the east in the Conococheague formation by a new and different trilobite facies fauna. This fauna is made the basis for a new lower Franconian faunizone equivalent to the *Elvinia* unit in the standard sequence. Trempealeauian trilobites are identified from the upper Conococheague formation.

INDICATIONS OF A LARGE COELACANTH FISH IN THE PERMIAN VALE FORMATION OF TEXAS

John Andrew Wilson
Dept. of Geology, The University of Texas, Austin, Texas

The discovery of shield-shaped bones bearing blunt or rounded conical, cap-shaped teeth, in an unnamed limestone member of the Vale formation of the Clear Fork Group of Runnels County, Texas, enables the author to suggest that they are tooth plates of the copula and/or branchial arches of a large coelacanth fish. Completely disassociated skull bones occur with the tooth plates, but efforts to find a sufficiently complete specimen for identification have been unsuccessful.

Smaller tooth plates of identical structure which may belong to *Spermatodus pustulosus* Cope have been found in the Wichita formation of Archer County, Texas.

PRELIMINARY REPORT ON A TORREJONIAN FAUNULE FROM NEAR ANGELS PEAK, SAN JUAN BASIN, NEW MEXICO

Robert W. Wilson
Museum of Natural History, University of Kansas, Lawrence, Kans.

In 1916, Walter Granger obtained a fragmentary mammalian fauna of Torrejonian age from the Nacimiento formation as exposed near Angels Peak in the San Juan Basin of New Mexico. Only a few genera were identified, and the fossils were found scattered through several hundred feet of the section. Recently, the University of Kansas recovered about 145 determinable specimens from a locality in the same area. Considerable importance is attached to the present collection because it is not only more diverse than that obtained previously, but also because it was obtained from a single stratigraphic level in a geographic area so small as to approach quarry conditions. Our collection was made approximately at the upper limit stratigraphically of the fossiliferous beds searched by Granger.

The faunule demonstrates clearly the Torrejonian age of the level concerned, but its exact position in time has not been determined. Certain characteristics suggest a slightly different age or, less likely, a slightly different facies, than the collections made farther south and southeast in the better-known sections of the Nacimiento. For example, in respect to size, many of our specimens are close to or below the minimum recorded for those of comparable species obtained elsewhere in the basin.

The faunule consists of approximately: Arctocyonidae, 33 per cent; Hyopsodontidae, 21 per cent; Phenacodontidae, 18 per cent; Periptychidae, 15 per cent; Miacidae, 4 per cent; and others 9 per cent. A generic list of mammals follows:

ptilodontid	*Claenodon?*	*Mioclaenus*
Palaeoryctes	*Tricentes?*	*Ellipsodon*
Pentacodon	*Chriacus*	*Protoselene*
Indrodon	*Deltatherium*	*Tetraclaenodon*
Primates?	*Triisodon?*	*Coriphagus*
Conoryctine?	*Goniacodon*	*Anisonchus*
Psittacotherium?	*Didymictis*	*Periptychus*

BIOGEOGRAPHY AND THE NATURE OF CONTINENTS

Albert Wolfson
Department of Biology, Northwestern University, Evanston, Ill.

The prevailing hypothesis to account for the distribution of fossil and living organisms is that of Matthew. This theory postulates the origin of many groups of terrestrial organisms in holarctic centers and their subsequent dispersal, in many cases, throughout the world. The salient feature in Matthew's theory is the rejection of all land bridges between the Old World and the New World except between Asia and North America at Bering Strait. With this single northern connection and those that exist (or existed) between northern and southern continents, the varied distribution patterns of many groups of organisms are explained.

Within recent years Matthew's theory is being seriously challenged by two types of studies. One type comprises new analyses and interpretations of the origin, distribution, and dispersal of various kinds of organisms. These studies point to tropical centers of origin, or at least origin in low latitudes. This raises the question of the suitability of the Bering Strait bridge as a passageway for originally tropical forms. The second type of study comprises experimental studies on the role of day length in reproduction in both plants and animals, and also its effect on other physiological phenomena. The results of these studies raise the question as to whether the day-length conditions at the Bering Strait bridge would have permitted the passage of the numerous forms that presumably crossed it.

On the basis of the results of these recent studies it would seem that future biogeographical studies cannot avoid the use of the multiple geological hypotheses of permanence, drifting, and foundering.

STRATIGRAPHY OF PALEOZOIC AND MESOZOIC ROCKS IN THE PIEDRA RIVER CANYON, ARCHULETA COUNTY, COLORADO*

Gordon H. Wood
U. S. Geological Survey, University Station, Albuquerque, N. Mex.

Sedimentary rocks exposed along Piedra River Canyon range in age from Cambrian (?) to Cretaceous and are underlain by Precambrian igneous and metamorphic rocks. Sedimentary formations are described and correlated with those of adjacent parts of Colorado and New Mexico.

The Entrada sandstone of the Upper Jurassic overlaps the Triassic and Paleozoic formations from southwest to northeast. Near Weminuche Creek it rests on Precambrian metamorphic rocks.

Possible extent of the area of overlap is shown on a regional map. The time of overlap, and the stratigraphic relations associated with it in the Piedra River Canyon differ from those known in the Brazos uplift and the Nacimiento Mountains of north-central New Mexico. These differences are described, and their relative positions in time and space are interpreted.

* Published by permission of the Director, U. S. Geological Survey.

REGIONAL GRAVITY STUDY OF THE APPALACHIAN MOUNTAIN SYSTEM

George P. Woollard
Dept. of Geology, University of Wisconsin, Madison, Wis.

A regional gravity network consisting of several thousand observations has been established over the Appalachian Mountain system. The area covered extends from the Gulf of Mexico and from the Allegheny Mountain Front to the Atlantic Coast. Simple Bouguer anomalies indicate the presence of two major gravity structures, a pronounced gravity minimum strip and an associated maximum strip, which parallel each other and the visible geologic structure. Although other gravity structures are present these two dominate the area. The anomalies cannot be attributed to the density of the surface rocks and are believed to reflect a thickening and thinning of the upper crust of the earth. In the mid-Appalachian area the magnitude of the gravity minimum is about −80 mgals and that of the gravity maximum approximately +40 mgals. On the basis of these data and a density contrast of 0.3 between upper granitic and lower more basic crustal material, a relief of about 9.5 kms is indicated on the base of the granitic layer. In southern Quebec this gravity pattern merges with a similar pattern following the St. Lawrence River Valley. In the far south the pattern dies out just beyond the Coastal Plain overlap. There is no evidence that the gravity pattern associated with the Appalachian Mountain system is continuous with that associated with the Quachitia Mountains on the western side of the Mississippi Embayment. Instead the structural trends indicated by gravity for each of these tectonic provinces appear to intersect at right angles. If there is a structural syntaxis, it appears to be similar to that observed at the junction of the Kurile and Aleutian island arcs.

GEOLOGY OF THE SILVER LAKE TALC AREA, SAN BERNARDINO COUNTY, CALIFORNIA

Lauren A. Wright
California Division of Mines, Ferry Building, San Francisco, Calif.

The commercial talc-tremolite deposits near Silver Lake are within a persistent feldspar- and diopside-rich member of a highly metamorphosed Precambrian sedimentary series. The deposits are elongate and lenticular and represent nearly complete replacement of carbonate strata. Other metasediments in the series include vitreous quartzite; marble containing disseminated forsterite, serpentine, chondrodite (?) and talc; quartz-muscovite schist; and quartz-biotite schist.

The quartz-biotite schist is commonly migmatitic; it also contains masses of microcline-quartz gneiss. An andesine-biotite-hornblende lamprophyre occurs as irregular bodies and dikes within the metasediments. Quartz diorite, which locally grades into and intrudes the lamprophyre, is the most extensive rock in the area. It intrudes the metasediments as sills and surrounds large residual metasedimentary islands. All these metasedimentary and igneous rocks have been intruded by felsic dikes. The metasediments, in general, dip uniformly southward, as do planar structures in the gneiss, lamprophyre, and quartz diorite.

The commercial deposits consist mostly of tremolite, but talc concentrations are common near the walls and are apparently alterations of tremolite along shear zones. The tremolite rock contains local residual masses composed of earlier metamorphic minerals. Forsterite (?), the first of these early minerals to form, has been partly to wholly replaced by talc and tremolite of an early generation; calcite and serpentine have locally replaced this tremolite. Serpentine veinlets intricately traverse the residual masses but do not extend beyond their borders. The late-generation tremolite formed contemporaneously with the intrusion of felsic dikes.

JADEITE PROBLEM

Hatten S. Yoder, Jr.
Geophysical Laboratory, 2801 Upton St., N.W., Washington, D. C.

The jadeite problem is reopened, and new data are presented which redefine the probable stability range of jadeite. The mineral is known to occur in only three places: as small masses in serpentine with albite, or nepheline, or both, in Burma, and with albite and quartz in Japan. No specimens have been found *in situ* in the Central American occurrence. The interest in jadeite is mainly due to the theory that it is a high-pressure mineral. If a reaction is known to be possible on other grounds, it will proceed under pressure in the direction of smaller volumes. However, the mere fact that the supposed products are of smaller volume than the reactants is not sufficient basis for inferring that the reaction will take place. All attempts to synthesize jadeite, even at pressures up to 4000 atmospheres, have been unsuccessful.

Although no direct structure determination appears to have been made, the common assumption that jadeite has a structure similar to diopside is justified by an indirect method. It is suggested that the co-ordination of sodium is probably less than normally assigned and that the "excess" aluminum occupies silicon positions.

The temperature of formation is believed to be less than 800°C. since the mineral melts metastably at a temperature at least as low as 800°C; it occurs with low-temperature albite (<700°C); it occurs in a reaction zone against serpentine (<500°C); its chemical equivalents, nepheline + albite, are stable in the presence of water down to 600° and 3000 atmospheres; and its glass fails to crystallize dry below 800°.

A new analysis of jadeite and data on the diopside-jadeite and acmite-jadeite joins are given. The jadeite problem is considered to be distinct from the eclogite problem.

ABSTRACTS OF PAPERS PRESENTED AT MEETING IN BERKELEY, APRIL 15–16, 1949

CORDILLERAN SECTION OF THE GEOLOGICAL SOCIETY OF AMERICA

MINIATURE CAULDRONS

Arch R. Addington
Fresno State College, Fresno, Calif.

The development of cauldrons in the solid rock of stream channels occupied by swift streams is well known. This paper deals with a series of small cauldronlike depressions, exhibiting linear arrangement, and with few exceptions having the characteristically developed profiles of larger cauldrons, formed in the channels of swift streams.

Miniature cauldrons are limited to a short expanse of rock outcrop, are closely spaced, their basins contain only angular fragments resulting from granular disintegration of the bedrock, their linear arrangement and development are independent of joint fractures, and their numbers (209 were measured) make them unique physiographic features.

The writer believes that water derived from melting snow is possibly the principal factor in their formation.

These features are located in the Sierra Nevada, near Huntington Lake, California, at an elevation of 7100 feet, where the snow pack may range from 70 to more than 100 inches per season.

FAULT PATTERN OF SOUTH-CENTRAL OREGON

Ira S. Allison
Oregon State College, Corvallis, Oregon

The abundant faults in south-central Oregon comprise two principal sets which intersect in a diamond-shaped pattern that suggests shearing. One set trends northwesterly, and the other northeasterly, although considerable variation occurs. The resulting elevated fault blocks, such as Abert Rim, Hart Mountain, Steens Mountain, and Winter Ridge, and rift valleys, such as the basins of Goose, Summer, and Abert lakes, are familiar to many geologists. Little known, however, is the abundance of small, closely spaced fault scarps on the high lava plains of the region. Many of these faults, though easily discernible on aerial photographs, have small throw so that their scarps are inconspicuous and easily overlooked on the ground. They are sufficiently numerous locally to be a fraction of a mile to 1–2 miles apart. Their pattern and general distribution in the region furnish clues to the structural history of the northern border of the Great Basin.

EOCENE AND OLIGOCENE FORMATIONS IN THE WESTERN GREAT BASIN

Daniel I. Axelrod
University of California, Los Angeles, Calif.

There have been only two formations in the western Great Basin whose older Tertiary age has been definitely established by fossil evidence: the "Martinez" formation (Paleocene) on the margin of the Mohave Desert and the Titus Canyon formation (Oligocene) near Death Valley. Three other formations are now considered older Tertiary on paleobotanical evidence.

The Mohave formation described by Fairbanks (but named by Smith) from El Paso Mountains was originally considered Eocene on the basis of two plants, but this assignment has not generally been accepted. An Eocene age is clearly demonstrated by a small flora (*Anemia, Anona, Myrica, Persea, Parathesis*) whose species resemble those now in the warm-temperate to subtropical forests of Mexico and Central America.

The Alta andesite near Virginia City was earlier considered Middle to Upper Miocene on the basis of a small flora in the Sutro member. New material shows that the flora (*Castanopsis, Fokienia, Quercus, Pseudolarix, Rhus*) largely has its modern affinities with the warm-temperate forests of southeastern China. This suggests the flora is not younger than Oligocene.

The Lower Cedarville formation in the Warner Mountains of northeastern California has a large flora dominated by temperate to warm-temperate plants (*Alnus, Berchemia, Cercidiphyllum, Diospyros, Gilbertia, Magnolia, Mallotus, Metasequoia, Tilia, Zelkova*) which find most of their living counterparts in eastern and southeastern China. This flora is older than the Lower John Day (Bridge Creek) and is apparently mid-Oligocene in age.

VOLCANIC ROCKS IN THE CANDELARIA DISTRICT, WEST-CENTRAL NEVADA

Julian D. Barksdale
University of Washington, Seattle, Wash.

The volcanic sequence in the Candelaria district, west-central Nevada, rests with angular unconformity on Ordovician (?), Permian, and Triassic rocks. The volcanics are fresh and unmineralized and are assumed to be Tertiary and Quaternary. The sequence can be divided into five distinct groups from oldest to youngest: (1) 1000–1250 feet of light-colored, vitroclastic, dacitic and rhyolitic tuffs, gray to black pseudovitrophyre, cream-colored porcellaneous rhyolitic rock, and a gray to white pumice tuff-breccia. One disconformity and one angular unconformity can be mapped within the group. Nuées ardentes type eruptions formed the pseudovitrophyre and part if not all of the cream-colored rhyolitic rock. (2) 80–200 feet of hypersthene basalt, basalt tuff, and breccia apparently conformable on (1); (3) following a period of tilting and erosion, 350 feet of dacitic rocks: vitroclastic tuffs, a rose-gray welded tuff simulating a flow rock, and at least two true flows; (4) thin mudflow breccia, almost entirely gray to red andesitic material erratically covering the older volcanics; (5) series of black, coarsely vesicular olivine basalt flows aggregating less than 100 feet in thickness.

STRATIGRAPHY AND STRUCTURE OF THE CAPITOLA QUADRANGLE, CALIFORNIA

Charles Noble Beard
Fresno State College, Fresno, Calif.

The structure of the central and southern portions of the quadrangle is that of nearly horizontal beds with general dips of 3°–4°. The northern third of the area has numerous minor anticlines and synclines developed in the foothills of the Santa Cruz Mountains. A few normal faults appear in the strata in the northern region.

The formations of the quadrangle range from Late Tertiary to Recent and are entirely soft sedimentary rocks. The Purisima formation (Pliocene) outcrops over most of the northern area and has two major subdivisions. The lower beds are largely marine sandstone and silt, with a possible eastern eolian equivalent; while the upper Purisima is chiefly continental coarse sand and gravel with subangular and subrounded pebbles. The prevailing formation in the south is a red quartzose sand which J. E. Allen has described and named as Aromas Red Sands (Pleistocene) from outcrops in the San Juan Bautista quadrangle. These beds are abundantly cross-bedded and are undoubtedly of eolian origin.

A major stratigraphic problem concerns determination of marine terrace deposits. Numerous accumulations of Pleistocene to Recent shells up to 8 feet thick on the tops of bench levels indicate marine deposition. Further evidence of marine origin is found in probable beach sands now occurring at 80 feet to 200 feet above sea level and containing large amounts of magnetite sand similar in composition to modern beach sand near by.

EARTHQUAKES AND ROCK CREEP (Continued)

Hugo Benioff
Seismological Laboratory, 220 North San Rafael Ave., Pasadena 2, Calif.

In the preceding paper of the same title read at the 1948 meeting of the Seismological Society of America, a method was described for determining the elastic-rebound strain increments associated with earthquakes of a particular fault system, based upon the modified instrumental magnitude scale of Gutenberg and Richter. It was shown that a graph of the accumulated increments plotted against

time for a given sequence of aftershocks or earthquakes represents the creep behavior of the fault rock. A number of examples were presented.

This study is continued. The aftershock sequence of the Long Beach earthquake has been extended from 10 days to 200 days. Graphs of three additional aftershock sequences are shown. In one of these, the elastic afterworking exhibits simple compressional creep recovery only. In the other two, the recovery has a dual form similar to the one found for the Long Beach sequence in which the first phase represents compressional creep and the second phase represents shear creep.

More elastic-rebound increment curves associated with earthquake sequences are presented. In addition to the constant-flow and the strain-hardening creep types found in the earlier study, a creep flow with an exponentially increasing rate has been found in several sequences having hypocenters of intermediate depths. This type of creep is characteristic of substances maintained at temperatures above the strain-hardening temperature limit. Additional evidence is offered in support of the earlier conclusion that the South American and Tonga deep-focus sequences represent single mechanical structures with linear dimensions of approximately 4400 km. and 2500 km. respectively. A causal relationship is suggested for the geographic association of deep-focus earthquakes with oceanic deeps.

DIKE COMPLEX IN THE TURTLE MOUNTAINS, EASTERN SAN BERNARDINO COUNTY, CALIFORNIA

Charles W. Chesterman
Division of Mines, San Francisco, Calif.

Recent field investigations of the perlite deposits in the Turtle Mountains, eastern San Bernardino County, California, disclosed a group of intrusive complexes of variable size and composition. One rhyolite and dacite dike complex mapped in detail measures 170 feet in length, has a crude hour-glass shape in ground plan, and is 15–50 feet wide. The rhyolite forms the outer margin, while the dacite occupies the interior portions of the complex. Field relations and examinations of thin sections indicate that the rhyolite is later. Contacts between the rhyolite and dacite are sharp. Chilled contacts are absent.

The complex intruded a pumiceous hornblende rhyolite breccia and formed a zone of alteration in the latter ranging from 5 to 30 feet in width. At the contact a dark, dense, brownish glass formed. This glass grades outward into unaltered pumiceous hornblende rhyolite breccia. Jointing in the altered hornblende rhyolite tends to conform with the steep walls of the complex.

LEONARDO DA VINCI AS A GEOLOGIST

Thomas Clements
University of Southern California, Los Angeles, Calif.

Although Leonardo da Vinci has been considered by some as a dilettante in the field of science, his scientific achievements have never been equaled by those of any other single individual. Outstanding as a painter and sculptor, he was also an engineer of great ability, an architect, a physicist, an anatomist, a botanist, a zoologist, a mathematician, and a geologist. He has been called by one recent writer the "Father of Paleontology." The average geologist of today, if he thinks of Da Vinci at all as a scientist, thinks of him as a rule only as someone who understood the meaning of fossils. Da Vinci went much further than this: his ideas on geologic time and processes, even including isostatic adjustment, are strikingly modern.

GRANITIZATION IN THE SWAUK FORMATION NEAR WENATCHEE, WASHINGTON

Howard A. Coombs
University of Washington, Seattle, Wash.

In the geographical center of the State of Washington the Swauk formation is a large lithologic unit in the eastern portion of the Cascade Range. This formation is essentially arkoses and sandstones with lesser quantities of clays, shales, and conglomerates, all of lower Eocene age.

Along the axis of an anticline 2 miles south of the City of Wenatchee, the arkoses have been transformed, locally, into a rock having the composition and texture of many granodiorites. The various steps in the granitization process can be traced from the initial stages wherein the quartz is enlarged by secondary growths and the plagioclase is rimmed with clear albite to the final stage resulting in a coarse-grained rock of interlocking crystals devoid of interstitial matter.

In the intermediate stages the clastic grains still reveal their original shapes although incorporating or rejecting much of the interstitital matter now in the form of an intergranular film. The resulting textures show very crenulated crystal boundaries with numerous inclusions or intergrowths or both.

This locality is thought to be noteworthy because the successive steps in the granitization process are preserved in the textures of the rocks and because the process was carried on at low temperatures with a small quantity of solutions needed.

NEPHRITE JADE AND ASSOCIATED ROCKS OF THE CAPE SAN MARTIN REGION MONTEREY COUNTY, CALIFORNIA

R. A. Crippen
California State Division of Mines, San Francisco, Calif.

Pebbles and boulders of green nephrite, in the shingle of beaches near Cape San Martin, are found adjacent to bedrock occurrences in the sea cliffs.

At Cape San Martin pale botryoidal nephrite forms part of the altered white aureole around a mass of gray Franciscan rock isolated in a serpentine intrusion.

North of Cape San Martin to Plaskett the sea-cliff rocks, in a section 1½ miles long and several hundred feet thick, are of unusual appearance, dark-gray and schistose with splotches, streaks, and lenses of whitish material. Schistosity and white streaking are parallel to an extensive, overlying sill-like body of serpentine. Bedded Franciscan sediments lie above the serpentine.

In thin section the schistose rocks are revealed as mylonites with varying degree of recrystallization in the whitish lenses. Some of the lenses in the mylonite at the Plaskett locality are nephrite; the largest is 10 feet wide by over 15 feet long. They are near serpentine which was intruded after mylonization.

VERDI, NEVADA, EARTHQUAKE OF DECEMBER 29, 1948

Vincent P. Gianella
University of Nevada, Reno, Nev.

Verdi, Nevada, was shaken by a series of earthquakes beginning on the evening of December 27, 1948. These were followed by many aftershocks. At 4:53 a.m. (P.S.T.) December 29 the strongest shock of the series toppled chimneys and did other damage in Verdi. The intensity was probably 6½ or stronger. Large boulders were dislodged from the mountain side in the Truckee River canyon on Highway 40 near the California-Nevada State line (120th Meridian). Cracks formed in the highway pavement. Water levels were affected in water wells both in Verdi and in Reno. Many of these shocks were felt in Reno, 10 miles to the east, with resulting minor damage. Several hundred aftershocks have been recorded on the seismographs at the University of Nevada station. Aftershocks were still continuing early in February. The strongest disturbances were in the vicinity of Verdi, and the seismograms of the University station indicate an epicenter within 12 or 15 miles of Reno. Probably the immediate cause of these earthquakes was movement along one of the faults on the eastern front of the Sierra Nevada, a short distance west of Verdi.

MINERALIZATION RELATED TO GRANITIZATION

G. E. Goodspeed
University of Washington, Seattle 5, Wash.

Mineralization in the form of small veinlets or disseminated sulphides is common to many regions of granitization. In some areas, as for example at Cornucopia, Oregon, field and petrographic evidence clearly shows that it is a late phase of granitization and rheomorphism. Zones of intense min-

eralization owe their localization to fracturing, shearing, or to rocks favorable to replacement. The large quartz veins of Cornucopia have been controlled by post-granitization shearing, while the magnetite deposits of eastern Okanogan County, Washington, were formed by the replacement of limestone lenses adjacent to an area of syenitization.

For many decades the sources of emanations or hydrothermal solutions which have caused mineralization have been assumed to have originated from slowly crystallizing magmas. Although this hypothesis has cogent supporting evidence in regions of definitely proved orthomagmatic intrusions, it is not adequate for areas where detailed field and petrographic studies indicate that the granitic masses are of metamorphic rather than of magmatic origin.

The process of granitization envisages the transformation into granitic rocks of the material originally deposited in a geosynclinal prism. Such a process would bring about a regional redistribution of certain chemical elements. It should be emphasized that kaolinitic material so abundant in a sedimentary series contains about 14 per cent water. The change of kaolinitic material to feldspars must drive off this water. Water so released by granitization can easily become the source of hydrothermal solutions to produce mineralization.

Although in some ore deposits the metallization is a direct concentration of metallic elements brought about by granitization, in others the source of these elements probably was from beneath a geosynclinal prism.

GEOLOGICAL PROBLEMS CONNECTED WITH FLOOD CONTROL PROJECTS IN THE CENTRAL VALLEY OF CALIFORNIA

C. P. Holdredge
2931 Highland Avenue, Sacramento, Calif.

Streams flowing into the Central Valley of California from the surrounding mountainous areas are being studied by the Sacramento District, Corps of Engineers, for the purpose of developing flood-storage reservoirs as a supplement to levee protection. The studies present geological problems involving foundations, reservoir tightness, silting, runoff, ground water, and construction materials.

The youthful topographic development of the Mesozoic and Tertiary terrain of the Coast Range north of San Francisco precludes the development of reservoirs or of outstanding damsites by differential erosion. Satisfactory construction materials are scarce. Sites on the Sacramento River between Redding and Red Bluff, and on its tributaries from the western slopes of Mt. Lassen, present problems of strength and permeability of the volcanic sediments of the Tuscan formation (Pliocene).

Streams flowing from the Sierra Nevada are characterized, in the foothill areas, by reservoir and damsites developed largely by differential erosion of the underlying granitic, and Tertiary to Quaternary sedimentary rocks. The sites underlain by granitic rocks are usually wide with relatively deep overburden; those underlain by metamorphic rocks reveal complicated structural conditions; while many sites underlain by the young sediments yield seepage problems.

Reactivity between aggregate materials and high-alkali cements is a problem. The discovery and development of satisfactory fill materials within economic distance of the sites presents problems in all areas.

OCCURRENCE OF LEONHARDITE

C. Osborne Hutton
Department of Mineral Sciences, Stanford University, Stanford, Calif.

Isolated crystals and veinlets of leonhardite have been found in a fine-grained greenish-gray graywacke from Otama, Southland, New Zealand, and in this rock the isolated crystals appear to represent replacement of original clastic plagioclase. The optical properties suggest that the zeolite is leonhardite rather than laumontite, a mineral of similar composition but containing a slightly higher percentage of water. The following optical properties have been determined:

$$\alpha = 1.506, \beta = 1.514, \gamma = 1.515, \gamma - \alpha = 0.009, 2V = 21° \pm 2°$$

Although this occurrence is only of local importance, both leonhardite and laumontite have a much wider distribution than has been supposed, and leonhardite is frequently found in altered graywackes and similar rocks that originally contained calcic plagioclase. If such rocks are subjected

to very low-grade dynamothermal metamorphism the original plagioclase may be completely altered to leonhardite (or laumontite) rather than to albite, which this zeolite closely resembles in thin section. A mistake in determination would seriously affect the understanding of the mineralogical transformations that had taken place under stress and, still more important, the composition of the unaltered rocks.

It is believed that leonhardite (or laumontite) has been incorrectly diagnosed as albite in a number of instances.

SORTING OF SEDIMENTS IN THE LIGHT OF FLUID MECHANICS

Douglas L. Inman
Scripps Institution of Oceanography, La Jolla, Calif.

Observations show that a physical relationship exists between the sorting, skewness, and median diameters of sediment samples from various areas. The general relationship of the Trask sorting coefficient to median diameter appears to be similar for all water environments investigated; the difference is mainly in the degree of sorting. Sediments with median diameters near the Wentworth grade of fine sand are the best sorted; finer and coarser sediments are more poorly sorted.

Investigation of the principles of fluid mechanics involved in the transportation and deposition of sediments indicates three primary controlling factors: degree of bottom roughness, settling velocity, and threshold velocity. The threshold velocity for a given size material is related to the fluid stress on the bottom necessary to cause initial movement of the sediment particles. Analysis of sedimentary processes in the light of these controlling factors indicates that the relationship between sorting, skewness, and median diameter of a sediment may furnish a clue to the conditions under which the sediment was transported and deposited.

PLIOCENE BRECCIAS IN THE AVAWATZ MOUNTAINS, SAN BERNARDINO COUNTY, CALIFORNIA

Richard H. Jahns and Albert E. J. Engel
California Institute of Technology, Pasadena, Calif.

A remarkable series of breccia lenses, interlayered with clastic sediments of Pliocene age, is exposed at the southeastern end of the Avawatz Mountains, San Bernardino County, California. These rocks constitute a part of the Avawatz formation of Henshaw.

The breccias are coarse-grained, and nearly all are essentially monolithologic. Most consist of angular blocks of white to gray limestone and dolomite set in a carbonate matrix, and typically they crop out as bold ridges and hillocks. Some consist almost wholly of quartzite fragments, and a few almost wholly of gneissic diorite or of other crystalline-rock fragments. They form tabular masses ranging from less than an inch to 300 feet or more in thickness and are clearly interstratified with much finer-grained conglomerate, arkose, sandstone, siltstone, and tuff. All these rocks are strongly folded and faulted and are overlain unconformably by coarse conglomerate of Quaternary age.

The Pliocene section appears to represent playa-lake and floodplain deposition, with intermittent addition of markedly coarser material from highland areas a few miles or even tens of miles distant. The breccia-making fragments may well have been transported as debris waves, and also in part as landslip masses. Some very large blocks, 100 feet or more in maximum dimension, may be of indirect tectonic origin. Aggregates of these blocks have many features in common with "boulder beds" and "block beds" described from other parts of the world.

SOME GEOLOGIC FACTORS IN SUBTERRANEAN CONSTRUCTION*

Geo. A. Kiersch
U. S. Corps of Engineers, Sacramento, Calif.

In the interest of national safety, the Corps of Engineers is charged with developing empirical criteria for "protective construction". Underground tests by the Corps outline the contributions of

* Findings expressed are those of the author and not necessarily views of the Corps of Engineers.

geology toward subterranean installations designed to resist stresses resulting from known and projected bombs and guided missiles.

Suitable subsurface openings will require a site rock of specified physical properties. Their size and cross-sectional shape will be controlled by the cover: its depth, physical character, planes of inherent weakness, and possible active stresses. Caves and abandoned mines may not be adequate.

Reconnaissance surveys may be restricted both areally and by acceptable rock types. Site selection will be influenced by the degree of rock deformation, attitude of bedding foliation, and water-supply requirements.

Geologic exploration and interpretation adequate to determine inherent structure, "ground-water level", a facies change, and weathering-alteration zones must precede final plant design. This will ordinarily involve regional studies and surface and subsurface detailed observations at the site.

An empirical pattern of rock failure resulting from dynamic stresses has been determined. The pressure front of a blast is considered to extend outward as an equal radial stress. Initial and most widespread failure is in tension and tangent to this front. Shear planes develop within a smaller nner zone analogous to the manner of failure by conventional static loading.

BASIN RANGE FAULTING NEAR SALT LAKE CITY, UTAH

R. E. Marsell
University of Utah, Salt Lake City, Utah

In spite of widespread interest for three-quarters of a century and the accumulation of a considerable literature, no detailed map has ever been published showing the Wasatch fault zone near Salt Lake City. In recent years, in connection with ground-water investigations, the author has made such a map on a scale of 1000 feet to the inch with a 5-foot contour interval. The findings assembled on the new map show: that (1) the Wasatch fault is not a single continuous plane of dislocation as previously described but is a complex zone of faulting in which both en echelon and step faults are common; (2) the faults tend to split or branch at bold salients of the range; (3) all faults die out with rapidly diminishing throw at the margins of the Salt Lake salient north of Salt Lake City; (4) no Basin Range fault exists along the southern margin of the Salt Lake salient as held by previous authors; (5) a new fault 8 miles in length, heretofore unrecognized, parallels the range front 1 to 3 miles west of the frontal scarp; (6) no Basin Range fault crosses the Salt Lake salient, as suggested by Beeson and Gilbert; and (7) the most recent movements in the fault zone did not affect all of the faults and was definitely a vertical uplift of the mountain block.

RIPPLE MARKS OF THE TRIASSIC MOENKOPI FORMATION

Edwin D. McKee
University of Arizona, Tucson, Ariz.

An analysis of ripple marks in the Triassic Moenkopi formation of Arizona and Utah has been undertaken because of the great abundance of these structures throughout the formation. More than 300 specimens have been examined and tabulated as regards (1) ripple type, (2) direction of movement represented, (3) size measurements, (4) ripple index, and (5) associated sedimentary features.

Two main types of asymmetrical ripple mark are recognized. Although both are widely distributed throughout the formation, they do not occur in the same beds or even in the same type of lithology. Evidence is presented indicating that one was formed on mud flats, probably tidal but possibly floodplain, whereas the other was formed in active stream channels. Less common are symmetrical ripple marks that indicate wave action. They are in the "mud-flat" type of deposit and locally are superimposed on current ripple marks.

Statistical studies of the directions of movement represented by asymmetrical ripple marks in selected localities and horizons suggest definite patterns of current movement.

PALEOZOIC ROCKS OF ANTELOPE VALLEY, EUREKA COUNTY, NEVADA

C. W. Merriam
California Institute of Technology, Pasadena, Calif.

Adding to knowledge of Great Basin stratigraphy a 10,000-foot Paleozoic section is described at Antelope Valley, Nevada. In these strata 19 successive faunal zones have been found, ranging from Upper Cambrian to Upper Devonian. Of particular interest from the structural point of view are thrust outliers of deformed Ordovician graptolite shales. The overthrust strata represent western graptolitic facies bearing distinctive faunules not known in the normal limestone section of Antelope Valley. Of the Ordovician and Silurian faunas in the normal section some are new or incompletely known. Geologic mapping and structural studies involved are a continuation of work previously done in the northern half of the Roberts Mountains quadrangle.

STRUCTURE, METAMORPHISM, AND GRANITIZATION IN PART OF OKANOGAN COUNTY, NORTH-CENTRAL WASHINGTON

Peter Misch
University of Washington, Seattle, Wash.

In the Riverside-Conconully area geosynclinal Paleozoic rocks have, presumably in Jurassic time, been intensely deformed, variously metamorphosed, and partially granitized. The lower part of the column comprises dolomites and limestones, mostly altered to marbles and containing fossils that indicate a Paleozoic—probably Devonian—age. Conformably above are rocks equivalent to part of the "Anarchist series". These are chiefly phyllites and biotite schists derived from argillite, and in the lower part there are actinolite-tremolite rocks, at least in large part derived from dolomitic clastic sediments. They pass laterally into amphibolites. Intrusive peridotites are serpentinized. Large recumbent folds have produced overthrusts. Other folds, mostly isoclinal, are steep. The highly variable trend averages southeast-northwest. Movement was to the northeast.

Synkinematic regional metamorphism varied in degree and was widely followed by static metamorphism. This is matched by a synkinematic and a static phase in a continuous process of metasomatic granitization. Augen gneisses, banded gneisses, and flasergneisses are synkinematic. Static granitization has formed small crosscutting replacement veins and patches partly preserving relict schistosity, and large masses of igneous-appearing granoblastic rocks of an uneven pattern which show all transitions into the country rocks. Relic zones of metamorphic Paleozoic rocks occur within granitized areas. At many places, static granitization has extended beyond the limits of synkinematic granitization. Local dilation dikes are interpreted as "rheomorphic". Selective granitization has spared marble anticlines and confined itself to synclinal areas of biotite schists, amphibolites, etc. Transformed amphibolites show gabbroid, dioritic, and granodioritic stages. Sodium metasomatism mostly preceded introduction of potash.

TITANOMAGNETITE ROCKS OF THE WESTERN SAN GABRIEL MOUNTAINS, CALIF.

Gordon B. Oakeshott
California Division of Mines, San Francisco, Calif.

Titanomagnetite, an intergrowth of ilmenite and magnetite, is widely distributed in association with andesine anorthosite, gabbro, and pyroxenite in the western San Gabriel Mountains a few miles north of Los Angeles. In these rocks titanomagnetite is an important accessory mineral, averaging less than 1% of the anorthosite, about 3–4% of the gabbro, and possibly 5–8% of the pyroxenites. The larger bodies of titaniferous iron ore occur as (1) irregular masses of pyroxene-titanomagnetite rocks in which the pyroxene has been replaced by chlorite and actinolite, (2) pegmatitic bodies including titanomagnetite with quartz, microcline, plagioclase, chlorite, and actinolite, and (3) deuterically altered lamprophyre and pyroxenite dikes.

A series of titanomagnetite rocks is recognized in which augite, chlorite, or apatite are characterizing accessories. A computed average of five such rocks, based on chemical analyses and microscopic study, showed a composition of 45% magnetite, 22% ilmenite, 12% chlorite, 6% apatite, plus actino-

lite, augite, and green spinel. Ilmenite and magnetite appear as an intergrowth ranging in proportion from less than 1:5 to as much as 3:4.

The sequence of crystallization of the minerals indicates that titanomagnetite is one of the latest to form. It is concluded that the ilmenite-magnetite intergrowth crystallized in the late deuteric-pegmatitic stage of igneous activity after crystallization of the orthotectic minerals and before the mesohydrothermal stage in which hot-water solutions became dominant. It was formed by deuteric replacement of the earlier pyrogenetic minerals, beginning before final consolidation of anorthosite and gabbro and continuing after those rocks had consolidated sufficiently to fracture.

STRUCTURE OF THE CANDELARIA DISTRICT, MINERAL COUNTY, NEVADA

Ben M. Page
Stanford University, Calif.

Rocks of the Candelaria silver district include Ordovician (?) Coaldale chert, Permo-Triassic Candelaria shale with basal grit, Tertiary tuffs and lavas, and Pleistocene (?) basalt.

Structural features comprise six groups: (1) numerous pre-Permian contortions and faults in Coaldale chert, (2) a steep, northward-dipping homocline in Candelaria shale, representing pre-Tertiary broad folding along an E.-W. axis, (3) three intersecting sets of steep fractures, filled by dikes, striking NW., E.-W., and NE., (4) reverse faults and minor thrusts of pre-Tertiary (?) age. Many of these trend E.-W., dip N. and show less than 200 feet displacement. The reversed faults include most of the argentiferous veins, some of which are mineralized bedding faults in Candelaria shale, (5) norma faults, generally striking NE. They are pre-late Pleistocene and locally offset Tertiary rocks 300–1200 feet but have only indirect topographic expression, (6) normal faults (late Quaternary), trending E.-W.

The two principal normal faults of (6) are "Basin and Range" structures with anomalous, E.-W. trends. They dip 40°–75° N. and 50°–75° S., respectively, and bound a narrow horst that appears to have been uplifted 300–800 feet. Faulting continued after formation of recent talus cones along the north flank of the horst.

CRETACEOUS, BAJA CALIFORNIA

W. P. Popenoe and Gordon Weir
University of California, Los Angeles, Calif.

Beds of late Upper Cretaceous age crop out at various localities along and near the Pacific coast of Baja California from Ensenada south to Arroyo Santa Catarina, approximately 200 miles below the International boundary. The uniform fauna including giant "*Parapachydiscus*" and other ammonites and a variety of other mollusks indicates contemporaneous age for the several exposures and not decreasing age southward as has been thought. Areas of late Cretaceous sediments in the vicinity of San Antonio del Mar have been greatly metamorphosed indicating intrusive activity in this part of the peninsula later than has been generally recognized.

DOLOMITE CRYSTALS OF TERUEL HABIT FROM LAKE ARTHUR, CHAVEZ COUNTY, NEW MEXICO

Austin F. Rogers
Stanford University, Calif.

One of the interesting habits of dolomite is the positive rhombohedron M $\{40\bar{4}1\}$ modified by the pinacoid c $\{0001\}$. Crystals of this habit are common in the region of Teruel, east-central Spain, and the varietal name teruelita was used by Calderon. They occur in massive gypsum.

Recently euhedral crystals of this habit ranging from 8 to 16 mm. in the longest dimension have been found at Lake Arthur, New Mexico. They also occur in massive gypsum. They are identified as dolomite by the specific gravity of 2.85 and interfacial angles cM and MM' and interzonal angles $[\bar{1}1\text{-}4]\wedge[12\text{-}\bar{4}]$. Plane angles expressed as interzonal angles are as characteristic as interfacial angles.

The writer found minute crystals of Teruel habit in the anhydrite of the salt mines of central Kansas and reported in 1910.

CHEMICAL FORMULA OF KEMPITE

Austin F. Rogers
Stanford University, Calif.

The so-called Alum Rock meteorite, a huge boulder of manganese ore found along Penitencia Creek in Alum Rock canyon, 5 miles east of the city of San Jose, California, furnished a number of manganese minerals. These include hausmannite, pyrochroite, and psilomelane as well as much altered manganese silicate identified as tephroite, but probably alleghanyite. The new mineral kempite, a basic manganese chloride, was described by the writer in 1924, and the formula $MnCl_2 \cdot 3MnO_2 \cdot 3H_2O$ assigned to it. Very small amounts of impure material, of the order of 50 milligrams, were available for the analysis. The relation of kempite to other minerals was overlooked at the time.

It seems likely that the formula of kempite is $MnCl_2 \cdot 3MnO \cdot 3H_2O$. It may be written $Mn_3(OH)_3Cl$ or $MnCl_2 \cdot 3Mn(OH)_2$. It is isomorphous with atacamite, as may be seen from the following comparisons of the axial ratios:

Atacamite	$Cu_3(OH)_3Cl$	$a:b:c = 0.657:1:0.749$
Kempite	$Mn_3(OH)_3Cl$	$a:b:c = 0.677:1:0.747$

Not many compounds of manganese and copper seem to be isomorphous, but the following examples may be cited:

(1) Pentahydrates of manganese and copper sulfates.
(2) Heptahydrates of manganese and copper sulfates.
(3) Hexahydrate double sulfates of ammonium-manganese and ammonium-copper.
(4) Manganese and copper chloroplatinate hexahydrates.
(5) Manganese and copper fluosilicate hexahydrates.

While the chemical properties of manganese and copper are not closely related, the atomic radii of the two elements are of similar magnitude.

GLACIOLOGICAL STUDIES ON THE SEWARD ICE FIELD, CANADA, DURING 1948

Robert P. Sharp
California Institute of Technology, Pasadena, Calif.

Initial phases in a continuing program of glaciological work on the Seward and Malaspina glaciers in Canada and Alaska are outlined.

Firn temperatures in the Seward ice field by mid-July were essentially 0°C. to a depth of 204 feet. Early eradication of the winter's chilled layer demonstrates the mild summer environment of this area. Firn densities range from 0.50 at the surface to 0.85 at 50 feet depth. Lowest densities, 0.47 to 0.46, are just under blue ice layers 4 to 10 feet beneath the surface. This relation and the undulatory upper surfaces of ice layers can be attributed to freezing of downward-percolating melt water along impervious strata. "Firn pipes", roughly cylindrical vertical masses of coarsely crystalline ice, are interpreted as former channels of meltwater percolation. During summer, water circulates freely through the firn with some layers making 300 to 600 cc. per hour for a collecting pan of 1439 sq. cm. The Seward ice field has a "water table" at a depth of 65 to 70 feet.

Excess accumulation for the budget year 1946–1947 was 17.5 to 18 inches of water. A preliminary figure for 1947–1948 is 23.5 inches. Wastage averaged 8 to 10 inches of water per month in midsummer.

Canadian seismic operations suggest ice 1600 feet thick 3 miles from the eastern edge of the ice field. Sonic echo-ranging soundings by Canadian personnel indicate promise for this method to depths of at least 450 feet. A reasonable transverse profile across a small valley glacier with a maximum depth of 700 feet was obtained by radar soundings but needs confirmation by independent means.

SIGNIFICANCE OF DEPTH CHANGES IN SUBMARINE CANYON HEADS

Francis P. Shepard
Scripps Institution of Oceanography, La Jolla, Calif.

Depth changes in the heads of submarine canyons have been determined in the past by the laborious method of wire soundings. It is now possible to use echo-sounding devices on small boats for frequent repetition of soundings along accurate ranges. By this means a series of four deepenings, presumably mud flows, have been discovered in four different branches of the La Jolla canyons. A maximum deepening of 10 feet was discovered shortly after unusually large waves. The deepening extended below the depth where waves could be reasonably expected to have had any effect, and it is believed that waves merely acted as a trigger to set off a slide in the canyon fill. Shoaling has taken place elsewhere, and the canyons are thought to have thick fills which may never be entirely removed by the occasional slumping of material along their floors.

Evidence is presented to indicate that the slides are common only in those canyons whose heads extend in close to the coast. The unfilled condition of canyon heads can be explained by the slides. On the other hand, the explanation of branching canyons cut scores of miles into rock shelves and cut to depths of thousands of feet below their surroundings as the work of mud flows or submarine landslides encounters serious difficulties. Consideration is given to a series of fault scarps with submarine continuations which lack even incipient submarine valleys on their submerged portions although extensive canyons exist on land. Computations are made to show the virtual impossibility of the development of the deep east-coast slope canyons by slides during the short periods of glacially lowered sea level when according to standard doctrine the outer shelves are thought to have been exposed.

ELEVATIONS OF SOME LAKE LAHONTAN SHORE LINES

George M. Stanley
Fresno State College, Fresno, Calif.

Lines of spirit levels were run to the shore lines of Quaternary Lake Lahontan in western Nevada in search of possible evidence of vertical dislocation by late Quaternary faulting or warping. In nine localities about Pyramid Lake and the Carson Desert the highest Lahontan beach has been measured at elevations ranging from 4374 to 4389 feet, A. T. This amount of variation does not at present seem to signify movements.

I. C. Russell's isolated levels of 1882 in Pyramid Lake basin have been tied in to modern bench marks.

The earliest historic (1870) shore line of Pyramid Lake, miles from the present, lowered lake in some places, contrasts greatly in appearance with the immediately higher and previous beaches. Groups of these, in turn, contrast with one another in age; the older are characterized by increased fine dirt and soil in the gravel and by darker shades of desert varnish on surface pebbles. The abrupt demarcations in these aspects, at critical levels up to 120 feet above present Pyramid Lake (ca. 3810), indicate a considerable period of general decline in lake level punctuated by upward resurgences. This does not favor the view that Lake Lahontan was at its maximum level as recently as 1000 or so years ago.

CUBIC PSEUDOMORPHS OF QUARTZ AFTER HALITE IN PETRIFIED WOOD

Lloyd W. Staples
University of Oregon, Eugene, Ore.

A portion of the Sweet Home, Linn County, Oregon, petrified forest east of the town of Holley has yielded petrified wood which is unique because of its inclusions. These inclusions are white cubes, some more than 6 millimeters in size, and consisting of a mosaic of quartz. They are found in *Platanus*, the sycamore, and more commonly in large concentric tubers which lack the cross grain due to wood rays. Frequently the quartz cubes have hollow centers, which are square in cross section. Some of the cubes are modified by the octahedron.

A study of the replacement leads to the conclusion that the quartz is pseudomorphous after hopper-shaped halite crystals, an occurrence not previously described. The presence of high concen-

trations of sodium chloride necessarily prior to the petrifaction of the wood indicates the probable existence of a marine lagoon, in this case most likely during the Oligocene. The generally accepted conclusion that hopper-shaped halite forms only on an evaporating surface is refuted by this occurrence because the halite is distributed all through the wood.

OCCURRENCE OF TEXAN PERMIAN AMMONOIDS IN ARIZONA

Alexander Stoyanow
University of Arizona, Tucson, Ariz.

Permian ammonoids, all important index fossils in the Tethyan stratigraphy of Texas, have not been known to occur westward beyond Alamogordo, New Mexico (located by C. C. Branson, described by A. K. Miller and E. J. Parizek). Until recently the Permian strata of Arizona, with other invertebrates common to both depositional regions abundantly represented, did not yield the ammonoids, and, since the Arizona Permian is uncommonly poor in fusulinids, the approximate correlation had to be made on brachiopods and gastropods of a long and not precisely established vertical range. A closer correlation is now possible through a find made by Donald L. Bryant in the Permian strata of Mustang Mountains, southeast of Tucson. The material available for studies is still fragmentary, and the ammonoids, in a close association with Lower Permian gastropods, seem to be restricted to a rather narrow zone of the entire Arizona Permian sequence. The writer was able to identify two species—*Paragastrioceras serratum* and *Popanoceras bowmani*—belonging in the Delaware Mountain and Word formations of Texas.

ENGINEERING GEOLOGY OF THE ISABELLA PROJECT, CALIFORNIA*

Ray C. Treasher
3932 12th Ave., Sacramento, Calif.

The Isabella flood-control project, which is being constructed by the Sacramento District, Corps of Engineers, consists of two earthfill dams, the main dam across the Kern River and the auxiliary dam across the Hot Spring valley about 35 airline miles northeast of Bakersfield. Subsurface exploration consisted of diamond-drill holes, trenches, shafts, and drifts. The granite bedrock is overlain by as much as 20 feet of decomposed granite in the main dam area and by as much as 100 feet of valley fill in the auxiliary dam area. The most serious foundation problem is the Kern Canyon fault zone that passes through the right abutment of the auxiliary dam. It is a high-angle thrust that dips west and is 800 feet wide. It consists principally of sheared granite decomposed to depths in excess of 80 feet. The east part of the zone, upon which the right abutment rests, consists of a large quartz vein, of intensely sheared, pulverized, and hydrothermally altered granite and quartz, and of a small lens of limestone and ferruginous clay. Although earthquake epicenters along the fault suggest activity at depth, there is no proof of movement at the dam site in historic times. Adequate earthquake protection is included in the dam design. Possibility of damaging percolation along the fault is decreased by a natural impervious blanket. Adequate supplies of construction materials are available.

THERMAL METAMORPHISM IN THE CENTRAL KUSKOKWIM REGION, SOUTHWESTERN ALASKA†

R. E. Wallace‡, W. M. Cady, E. J. Webber, J. M. Hoare
U. S. Geological Survey, Washington, D. C.

Examples of almost pure thermal metamorphism of interbedded graywackes, siltstones, and shales surrounding stocks of intermediate composition are found in the central Kuskokwim region of southwestern Alaska.

An aureole of metamorphic rocks surrounds each stock in the Taylor, Chuilnuk, Kiokluk, Horn,

---

* Published by permission of the District Engineer, Sacramento District, Corps of Engineers.
† Published with the permission of the Director, U. S. Geological Survey.
‡ Also the State College of Washington, Pullman, Washington.

and Russian mountains. The observed outcrop widths of these zones vary from less than 1000 feet to more than 3 miles. The greater apparent widths are in part the result of igneous contacts that dip at relatively small angles; probably the true maximum thickness of any metamorphic zone bordering stocks in this area is 5000 feet or less.

The following prominent features of alteration are noted: increase in abundance and grain size of biotite from the outside edge of the metamorphic aureole inward; development of cordierite metacrysts and recrystallization of quartz in the inner portions of the aureole. Cordierite metacrysts are prominent in several places where recrystallization of quartz has not obliterated the clastic texture. The greatest development of cordierite metacrysts, however, is accompanied by complete disappearance of the original clastic texture with production of a dense hornfelsic rock. In places such rock represents the maximum intensity of metamorphism. In other localities where the sediments are apparently less aluminous, complete recrystallization to a hornfels without cordierite metacrysts represents the maximum intensity.

In this region even the most intense thermal metamorphism would be classed as of relatively low or medium grade according to standards described by Harker.

GOLD AND SILVER CONTENT OF SOME TREES AND HORSETAILS IN BRITISH COLUMBIA

Harry V. Warren and R. E. Delavault
University of British Columbia, Vancouver, B. C.

An area known to contain many gold-bearing veinlets, and in which many prospect pits and trenches had been dug, was investigated. Overburden, usually 4 to 8 feet deep, and in part composed of glacial clay, wherever panned near bedrock, revealed the presence of gold. The amount of gold yielded by panning surface material was in most samples negligible.

Samples from five species of trees were carefully taken in a manner that appeared to eliminate danger of physical salting. Four collections of horsetails were also made from near-by ground which was, however, known to contain much more modest quantities of gold.

Careful analyses revealed the presence of gold in every sample but one. Control samples from nongold-bearing areas with similar climate in no instance provided weighable quantities of gold.

Silver was found in most plants including those growing in areas where there was no evidence of silver mineralization.

GEOLOGY OF SHASTA VALLEY AND THE ADJACENT CASCADES, NORTHEASTERN CALIFORNIA

Howel Williams
University of California, Berkeley, Calif.

The oldest rocks of the area are ?Paleozoic quartzites and metacherts near the foot of Mount Shasta. They are intruded by quartz monzonites of Jurassic age. Resting unconformably on these bedrocks are Upper Cretaceous sediments, exposed near Yreka and probably underlying most of Shasta Valley. These are overlain by coal-bearing fresh-water Umpqua sediments of Eocene age, above which lie Eocene to Miocene volcanic rocks belonging to the Western Cascade Series. These are dominantly andesitic, but range from basalts to rhyolites, and locally exceed 12,000 feet in thickness. Several denuded necks mark foci of eruption.

At the close of the Miocene, the beds were gently tilted to the east and northeast, and in places cut by faults trending slightly west of north. Thereafter a line of imposing volcanoes developed along the crest of the Cascade Range. The first of these High Cascade volcanoes were shields of olivine basalt; subsequently, steeper cones of andesite and dacite grew alongside them.

After the Pleistocene, new cones of andesite and basalt were formed, while extensive floods of olivine basalt drowned much of Shasta and Butte valleys and poured down adjacent canyons. Eruptions near Copco Dam impounded the Klamath River to produce a large lake. Much of this Recent activity occurred within the last millennium or two.

Shasta Valley and Butte Valley, bordering the Cascade Range, are structural depressions, the former dating back to the close of the Miocene, while the latter is bounded by well-preserved fault scarps of much later origin.

CRYSTAL SPRING FORMATION, SOUTHERN DEATH VALLEY AREA, CALIFORNIA

Lauren A. Wright
Division of Mines, San Francisco, Calif.

The known exposures of the Crystal Spring formation, the lowermost unit of the late pre-Cambrian Pahrump series, are confined to an irregular 70-mile, west-northwest trending belt in the southern Death Valley area of Inyo and San Bernardino counties, California. Sections of this formation are particularly well shown on the southeastern flank of the Panamint Range, in the Ibex, Alexander, and Silurian Hills, and in an east-west belt extending through the central portion of the Kingston Range. The Alexander Hills section, which is representative and is one of the most complete, contains 3000 ft. of Crystal Spring sediments. Here the Crystal Spring formation is underlain by early pre-Cambrian micaceous schist and granitic gneiss and is overlain by the late pre-Cambrian Beck Spring dolomite.

Members of the lower half of the formation consist successively of a basal quartzite conglomerate, coarse- to medium-grained feldspathic quartzite, shale, fine-grained, dense quartzite, and dolomite. These tend to persist throughout the southern Death Valley and Kingston Range area. Less persistent shale, quartzite, limestone, and dolomite members constitute the upper half of the formation. At all observed localities a diabase sill is at or slightly above the base of the lowermost carbonate member. Commercial talc and talc-tremolite bodies have formed along or near contacts between the diabase and the carbonate beds.

ONTOGENETIC VARIATION IN *EPONIDES MEXICANUS* (CUSHMAN)

Orville L. Bandy
University of Southern California, Los Angeles, Calif.

Eponides mexicanus (Cushman), an important Claiborne index foraminifer of the Gulf coast, occurs in considerable abundance in the upper part of the Lisbon formation, as exposed along Little Stave Creek, Clarke County, Alabama. A population study revealed the presence of numerous growth stages with striking attendant variations. Instead of a fairly uniform number of chambers per whorl throughout the ontogeny, as is the case in many species of smaller Foraminifera, there is a progressive increase in the number of chambers per whorl in *E. mexicanus* as whorls are added. Other associated variations include a marked increase in the amount of secondary thickening surrounding the umbilicus and, in the larger forms, an irregularity of chamber development.

The most important result of this investigation is to point out the obvious similarity between *E. mexicanus* (Cushman) and *E. guayabalensis* Cole. The earlier stages of *E. mexicanus* are quite different from *E. guayabalensis*, but as development continues in the former there is the appearance of conspicuous morphologic similarity between the two species. It is necessarily concluded that *E. guayabalensis* Cole (1927) is actually the gerontic form of *E. mexicanus* (Cushman) (1925) and is therefore placed in synonymy with it.

RHINOCEROS MOLD IN BASALT

Walter. M. Chappell, J. Wyatt Durham and Donald E. Savage
University of California, Berkeley, Calif.

A cavity in the basal part of a thick flow of the Miocene Columbia River basalts on the shore of Blue Lake, Washington, has been the subject of much informal controversy since its discovery in 1935. Because of its size and shape, and the occurrence in it of fossilized bones, this cavity has been regarded by some as the mold of a rhinoceros. Strong objections to this have been based on the impossibility of preserving animal tissue in molten lava.

The cavity was visited in 1948, a partial cast made, and the site examined. Bone was found imbedded in a matrix partially filling the left front leg. Spectrographic and petrographic examination of this matrix indicates that it was not derived from an interbedded soil below the cavity or from weathering of the basalt. The matrix appears to be of chemical origin. Apparent skin folds are preserved in several places and the three-toed character of the right front foot is demonstrable. All identifiable bone fragments are rhinocerotid in character and on the basis of size referrable to *Diceratherium*. The available evidence indicates to the authors that the cavity is the mold of a rhinoceros. Because of the occurrence of pillow structure in the base of the flow, it is suggested that preservation of the rhinoceros was due to conditions associated with the formation of the pillows.

PLEISTOCENE AVIFAUNA FROM KANSAS AND ITS ENVIRONMENT

Theodore Downs
University of California, Berkeley, Calif.

The Jones fauna of western Kansas, taken from a sink-hole deposit, includes over 100 skeletal elements of birds. A grebe, surface feeding and diving ducks, shore birds, upland plovers, a dove, blackbirds, lark buntings, a longspur, and indeterminate fringillids were identified. Other authors have reported mollusks, amphibians, and mammals from the fauna.

An upland grassland or prairie, possibly surrounding a lake or marsh habitat, was probably present during the life of the avifauna, in contrast to the relatively dry stream bed in existence in the area today.

CRYSTAL SPRING FORMATION, SOUTHERN DEATH VALLEY AREA, CALIFORNIA

Lauren A. Wright
Division of Mines, San Francisco, Calif.

The known exposures of the Crystal Spring formation, the lowermost unit of the late pre-Cambrian Pahrump series, are confined to an irregular 70-mile, west-northwest trending belt in the southern Death Valley area of Inyo and San Bernardino counties, California. Sections of this formation are particularly well shown on the southeastern flank of the Panamint Range, in the Ibex, Alexander, and Silurian Hills, and in an east-west belt extending through the central portion of the Kingston Range. The Alexander Hills section, which is representative and is one of the most complete, contains 3000 ft. of Crystal Spring sediments. Here the Crystal Spring formation is underlain by early pre-Cambrian micaceous schist and granitic gneiss and is overlain by the late pre-Cambrian Beck Spring dolomite.

Members of the lower half of the formation consist successively of a basal quartzite conglomerate, coarse- to medium-grained feldspathic quartzite, shale, fine-grained, dense quartzite, and dolomite. These tend to persist throughout the southern Death Valley and Kingston Range area. Less persistent shale, quartzite, limestone, and dolomite members constitute the upper half of the formation. At all observed localities a diabase sill is at or slightly above the base of the lowermost carbonate member. Commercial talc and talc-tremolite bodies have formed along or near contacts between the diabase and the carbonate beds.

ONTOGENETIC VARIATION IN *EPONIDES MEXICANUS* (CUSHMAN)

Orville L. Bandy
University of Southern California, Los Angeles, Calif.

Eponides mexicanus (Cushman), an important Claiborne index foraminifer of the Gulf coast, occurs in considerable abundance in the upper part of the Lisbon formation, as exposed along Little Stave Creek, Clarke County, Alabama. A population study revealed the presence of numerous growth stages with striking attendant variations. Instead of a fairly uniform number of chambers per whorl throughout the ontogeny, as is the case in many species of smaller Foraminifera, there is a progressive increase in the number of chambers per whorl in *E. mexicanus* as whorls are added. Other associated variations include a marked increase in the amount of secondary thickening surrounding the umbilicus and, in the larger forms, an irregularity of chamber development.

The most important result of this investigation is to point out the obvious similarity between *E. mexicanus* (Cushman) and *E. guayabalensis* Cole. The earlier stages of *E. mexicanus* are quite different from *E. guayabalensis*, but as development continues in the former there is the appearance of conspicuous morphologic similarity between the two species. It is necessarily concluded that *E. guayabalensis* Cole (1927) is actually the gerontic form of *E. mexicanus* (Cushman) (1925) and is therefore placed in synonymy with it.

RHINOCEROS MOLD IN BASALT

Walter. M. Chappell, J. Wyatt Durham and Donald E. Savage
University of California, Berkeley, Calif.

A cavity in the basal part of a thick flow of the Miocene Columbia River basalts on the shore of Blue Lake, Washington, has been the subject of much informal controversy since its discovery in 1935. Because of its size and shape, and the occurrence in it of fossilized bones, this cavity has been regarded by some as the mold of a rhinoceros. Strong objections to this have been based on the impossibility of preserving animal tissue in molten lava.

The cavity was visited in 1948, a partial cast made, and the site examined. Bone was found imbedded in a matrix partially filling the left front leg. Spectrographic and petrographic examination of this matrix indicates that it was not derived from an interbedded soil below the cavity or from weathering of the basalt. The matrix appears to be of chemical origin. Apparent skin folds are preserved in several places and the three-toed character of the right front foot is demonstrable. All identifiable bone fragments are rhinocerotid in character and on the basis of size referrable to *Diceratherium*. The available evidence indicates to the authors that the cavity is the mold of a rhinoceros. Because of the occurrence of pillow structure in the base of the flow, it is suggested that preservation of the rhinoceros was due to conditions associated with the formation of the pillows.

PLEISTOCENE AVIFAUNA FROM KANSAS AND ITS ENVIRONMENT

Theodore Downs
University of California, Berkeley, Calif.

The Jones fauna of western Kansas, taken from a sink-hole deposit, includes over 100 skeletal elements of birds. A grebe, surface feeding and diving ducks, shore birds, upland plovers, a dove, blackbirds, lark buntings, a longspur, and indeterminate fringillids were identified. Other authors have reported mollusks, amphibians, and mammals from the fauna.

An upland grassland or prairie, possibly surrounding a lake or marsh habitat, was probably present during the life of the avifauna, in contrast to the relatively dry stream bed in existence in the area today.

The upland plains type birds: *Bartramia longicauda* (Bechstein), *Calamospiza melanocorys* Stejneger, and *Calcarius* sp. are identified from the fossil record for the first time and have not been found in other Pleistocene assemblages in Florida, New Mexico, Oregon, or California.

MISSISSIPPIAN CUNEATE CORALS

W. H. Easton
University of Southern California, Los Angeles, Calif.

Several species of Mississippian corals have been described which are compressed on both alar sides. It is proposed that corals possessing this feature be termed "cuneate" to distinguish them from previously differentiated "calceolid" corals which are flattened on one side only (either the cardinal or counter side). The known Mississippian cuneate corals are either restudied or described in the text. Three distinct phylogenetic series of corals contain cuneate species. Evolutionary development of the character is considered where possible. It appears that this particular modification reaches its acme just before the extinction of each lineage. Philosophical implications of this multiple homeomorphy are discussed. Systematic revision of the following genera and species is required: *Cyathaxonia venusta, Hapsiphyllum calcariforme, Homalophyllites calceolus, Zaphrentisacutus, Z. clinatus, Z. compressa, Z. elliptica, Z. lanceolatus, Z. parasitica, Z. reversa,* and *Z. ulrichi.*

OCCURRENCE OF A QUESTIONABLE *ELPHIDIUM* IN THE EARLY TERTIARY OF CALIFORNIA

Joseph J. Graham
Stanford University, Calif.

A foraminifer which apparently combines characteristics of *Nonion* and *Elphidium,* two closely related genera of the family Nonionidae, occurs in Division E (Capay) of the type Meganos formation of California. Division E is considered to be correlative of the Wilcox Lower Eocene of the Gulf Coast.

As Cushman has stated, the evolution from *Nonion* to *Elphidium* is gradual, and it is difficult to distinguish some early species of *Elphidium* from *Nonion,* especially if the retral processes are not highly developed. If the Meganos species is definitely an *Elphidium,* then it marks the earliest Eocene occurrence of the genus on the West Coast and possibly one of the oldest in North America. Hitherto, the genus has not been recorded in California in strata older than the Poway conglomerate and in the Gulf Coast in sediments older than the Weches formation, both of which are correlated with the Claiborne Middle Eocene. In the eastern coastal plain the genus is not known from formations older than the Hornerstown of New Jersey, which is correlated with the lower Wilcox.

PHYLOGENETIC SIGNIFICANCE OF SOME PLIOCENE HORSES FROM MEXICO

John F. Lance
California Institute of Technology, Pasadena, Calif.

Differences of opinion exist concerning the phylogenetic relations and generic status of *Equus.* Recent studies agree in general as to the derivation of *Equus s.s.* from the subgenus *Pliohippus* (*Astrohippus*), but not as to the derivation or generic status of *Plesippus* and/or *Hippotigris.*

Fossil horses in the Yepomera (formerly designated Rincon) fauna of Chihuahua, Mexico, throw some light on this problem. A preliminary survey of the entire assemblage suggests a relationship to faunas from the Hemphill of Texas, Alachua-Bone Valley of Florida, and the Mt. Eden of California. The stage of evolution of the horses from Yepomera suggests that the Mexican occurrence is slightly younger than those mentioned, a conclusion not completely substantiated by the total fauna.

The four types of fossil horses present at Yepomera are: *Neohipparion* cf. *phosphorum* (Simpson), *Nannippus* cf. *minor* (Sellards), a new species of *Pliohippus* (*P.*) more advanced than *P. osborni* Frick, and a new species of *P.* (*Astrohippus*) more advanced than *P.* (*A.*) *ansae* (Matthew and Stirton). The Mexican pliohippines display quite *Equus*-like characters in the upper dentition. The fossil form referred to the typical subgenus is considered nearer *Plesippus* than any known Hemphillian form and is a likely ancestor of *Equus s.l.* It is concluded that existing horses have been derived from the typical subgenus of *Pliohippus,* which should include *P. osborni* and related forms, and that the group including *P.* (*Astrohippus*) *ansae* is not in the direct line of descent of any of the known Blancan or later horses.

CORRELATION OF THE PLIOCENE MAMMALIAN FAUNAS OF NEVADA

J. R. Macdonald
Museum of Paleontology, University of California, Berkeley, Calif.

A restudy of the Pliocene vertebrate faunas of Nevada has yielded several new records of species with high correlative value. Most previous age determinations have been substantiated and in some cases refined. New materials include:

Coal Valley Fauna: *?Rhyncotherium, Aelurodon, Nannippus tehonensis* (Merriam), *Pliohippus, ?Aphelops,* Camelidae gen. indet.

Truckee-Nightingale Road Fauna: *Pseudaplodon, Mylagaulus, Hystricops, Eucastor lecontei* (Merriam), *Osteoborus diabloensis* Richey, Tapiridae gen. indet., *Neohipparion, Ustatochoerus, Alticamelus.*

Smiths Valley: *Dipoides stirtoni* Wilson, *Osteoborus, Indarctos, Mammut* (*Pliomastodon*) *nevadanus* Stock), *Pliohippus* cf. *spectans, Prosthennops, Pliauchenia, Paracamelus.*

Yerington: *Dipoides stirtoni* Wilson, *Pliohippus* cf. *spectans.*

The following correlation is indicated:

Age	Nevada		West Coast	
Blancan	Wichman		San Joaquin Clay	
	Thousand Creek			
Hemphillian			Etchegoin	
	Smiths Valley, Yerington		Rattlesnake, Rome, Mullholland	
	Truckee-Nightingale Road	Chalk Spring	Siesta, Upper Ricardo	Black Hawk Ranch
Clarendonian	Fish Lake Valley, Cedar Mountain		Lower Ricardo	
	Coal Valley		Lower Chanac	Older Black Hawk Ranch

GENETIC LINES IN CALIFORNIA CRETACEOUS MOLLUSKS

W. P. Popenoe
University of California, Los Angeles, Calif.

A number of common molluscan genera well represented in California Upper Cretaceous deposits and ranging throughout much or all of the Upper Cretaceous section are composed of closely related and intergrading species and probably represent genetic lines. Specific differentiation within these genera apparently resulted from slow evolutionary change passed through in Upper Cretaceous time in the California region. Cryptogenetic stocks reaching California from outside during the Upper Cretaceous are a rather rare and unimportant element of the fauna. Recognition of these evolutionary stages is of practical value in local correlation. Several representative examples are described and illustrated.

SUBDIVISION OF THE LATE CENOZOIC OF THE SAN FRANCISCO BAY REGION

Donald E. Savage
Museum of Paleontology, University of California, Berkeley, Calif.

A study of the latest Cenozoic vertebrate faunas of the San Francisco Bay region indicates a threefold grouping. The oldest fauna of this grouping is correlated with the Blancan faunal age. The large Irvington fauna is post-Blancan and apparently earlier Pleistocene, based on the unprogressive character of certain species and on the absence of *Bison*. Faunas which include *Bison* are considered to be of later Pleistocene age. In the Bay region, the Blancan faunas occur in highly disturbed beds, the Irvington fauna is found in moderately disturbed beds, and the faunas containing *Bison* occur in relatively undisturbed strata.

SEISMOLOGICAL SOCIETY

DIRECTIONAL CHARACTERISTICS OF STRAIN SEISMOGRAPH PAIRS

Hugo Benioff
Seismological Laboratory, 220 North San Rafael Ave., Pasadena, Calif.

The directional characteristics of the in-phase and phase-opposition combinations of linear-strain seismograph pairs having relative orientations of 45° and 90° are discussed. The response of the 90-degree in-phase pair is of particular interest because it is zero for all shear waves and is independent of direction for longitudinal waves. This combination, therefore, provides a direct instrumental means for differentiating between Rayleigh waves and surface shear waves.

PLANS FOR THE EARTHQUAKE ENGINEERING RESEARCH INSTITUTE

John A. Blume
45 Second Street, San Francisco, Calif.

The Earthquake Engineering Research Institute has been incorporated as a nonprofit organization for continued research in engineering seismology. This institute, founded by the Advisory Committee on Engineering Seismology, will conduct investigations on a thorough and scientific basis, with the particular objective of developing practical and economical data on the location, design, and construction of buildings and other structures to resist earthquake motions and forces. The paper describes plans for the Institute, and some of the work necessary to bridge the gap between pure seismology and the optimum building regulations and design practices for the economical protection of the public against earthquake hazards.

FIRST MOTION FROM DEEP AND SHALLOW SHOCKS

Perry Byerly and J. Evernden
University of California, Berkeley, Calif.

An examination has been made of the first motion for 100 earthquakes which were well recorded at Berkeley with epicenters along the Pacific Coast from the Aleutians to Chile. These were earthquakes for which the depth of focus had been well determined. In most cases the nature of the first motion—compression or rarefaction—for shallow shocks in a given region was opposite to that of deep shocks.

NEVADA EARTHQUAKES

Perry Byerly and Carl Romney
University of California, Berkeley, Calif.

Results of a study of the seismograms of the earthquake centering near Verdi, Nevada, at 04:53, P.S.T., 29 December, 1948, are presented. The preliminary epicenter is at 39° 35′ N., 120° 08′ W., and the preliminary speed of P_n waves is about 8.1 km/sec. The direction of first motion recorded at various stations was consistent with the pattern usually obtained for California earthquakes. Locations of the epicenters of the principal foreshocks and aftershocks relative to the main shock indicate very little change in position.

LONG-PERIOD ACCELERATION MEASUREMENTS

C. H. Dix, L. P. Geldart, R. Ingram, S.J., and C. W. Faessler
California Institute of Technology, Pasadena, Calif.

Using a LaCoste and Romberg gravity meter, readings were taken every half hour for 72 hours immediately preceding full moon in the sub-basement of Mudd Laboratory at the California Insti-

tute of Technology and for 56 hours immediately following in the interferometer building on Mount Wilson. Observed values were compared with values calculated on the hypothesis of a rigid earth showing more yielding at Mount Wilson (22 per cent) than at Mudd (16 per cent). Effects due to ocean tides were calculated, and effects due to atmospheric variations were estimated but were found to be negligible. After the drift and earth-tide effects were removed, the residual data show residual periods of 24, 12, 6, and 2 hours, the 24-hour period being very strong at Mt. Wilson. The amplitudes are small enough so that simultaneous readings on two independent instruments would be necessary to make the 2-hour period significant.

PROPOSED TSUNAMI WARNING SYSTEM

Maurice Ewing, Ivan Tolstoy, and Frank Press
Columbia University, New York, N. Y.

A striking correlation between the occurrence of a short-period earthquake phase ("T" phase) travelling through the ocean with the speed of sound in sea water and the occurrence of tsunamis has been observed. The characteristics of the "T" phase are described, and the data upon which the correlation is based are presented. Although further study is needed, the evidence at hand warrants the inclusion of instruments suitable for recording the "T" phase in tsunami warning systems. It is quite possible that SOFAR listening stations would be valuable adjuncts in the detection of tsunami-producing earthquakes since they offer the best means of recording the "T" phase.

APPROXIMATIONS IN GEOPHYSICS

Beno Gutenberg
Seismological Laboratory, 220 N. San Rafael Ave., Pasadena, Calif.

A relatively large fraction of theoretical formulations as well as fundamental numerical data in geophysics are based on approximations. Unfortunately, in many instances this fact is not realized sufficiently. Examples related to a number of cases, especially concerning seismological problems, are given, and incorrect usage of the method of least squares as well as incorrect deductions based on calculated standard errors are discussed.

DISCUSSION OF THE CURRENT PRACTICE IN THE DESIGN OF STRUCTURES TO RESIST EARTHQUAKES

George W. Housner
California Institute of Technology, Pasadena, Calif.

Methods of design currently being used in California to render structures earthquake-resistant are described and discussed, and unsolved problems in engineering seismology are presented.

GROUND VIBRATIONS FROM EXPLOSIONS

B. F. Howell, Jr.
California Institute of Technology, Pasadena, Calif.

Records are presented of the three components of ground vibration taken at distances out to 3284 meters following small explosions of dynamite about 10 meters underground. Aside from reflected and refracted body waves, three principal pulses of energy are clearly discernible in the records, all highly dispersed: (1) a pulse whose motion is largely confined to the longitudinal component; (2) a direct elliptical motion on the longitudinal and vertical components; and (3) a retrograde elliptical motion on the longitudinal and vertical components.

The last of these is the ground roll of exploration geophysics. It is, in general, similar to a Rayleigh wave, though some modification of Rayleigh's theory is required to account for the low ratio of the vertical to the horizontal amplitudes of motion. The direct elliptical motion might be a kind of

Stoneley wave related to the interface at the base of the weathered surface layer. Neither it nor the pulse confined to the longitudinal component have been correlated adequately with existing theories of wave motion. The records are compared to ones similarly recorded and previously described by L. Don Leet.

The surface layer of the earth through which these waves appear to be transmitted is not necessarily homogeneous or isotropic, and certainly is not elastic; and hence the differences of the observed waves from the types of body and surface waves described by well-known theories are not surprising.

IMPULSIVE HYDRODYNAMICS OF A PARTIALLY FILLED CYLINDRICAL TANK AS WELL AS OF A CYLINDER SURROUNDED BY A FINITE DEPTH OF FLUID

Lydik S. Jacobsen
Stanford University, Stanford, Calif.

A horizontal impulsive linear displacement $f(t)$ is applied to the tank or to the cylinder. The velocity potentials of the fluids inside the tank as well as outside the cylinder are derived in terms of trigonometric functions of real arguments and Bessel Functions of imaginary arguments. Bessel Functions of the first kind are required to describe the fluid field inside the tank, and Bessel Functions of the second kind characterize the fluid field surrounding the cylinder.

Impulsive pressure distributions and their consequent summations on the cylindrical and bottom boundaries have been obtained.

Impulsive velocities at the free water surface have been calculated.

The theory applies to flat-bottomed cylindrical tanks subjected to impulsive earthquake motions in the horizontal direction as well as to cylindrical piers surrounded by water.

Experimental verification of the effective fluid mass inside a tank has been made.

DISCUSSION OF TRIPARTITE MICROSEISMIC MEASUREMENTS

L. Don Leet
Harvard Seismograph Station, Harvard, Mass.

There has been a tendency to overemphasize the accuracy of a tripartite station's determination of the bearing of a microseismic wave. Such a determination is based on the assumption that the time of passage of the crest of a specific advancing wave is uniquely observed at each instrument of the network. This is not the case, in general, where waves are approaching from more than one direction. There is compelling evidence that they are doing this in many, if not all, storms.

Specific cases are discussed of waves of the same period and waves of different periods crossing a tripartite network. It is concluded that routine averaging of intervals from time marks to the nearest crest or trough can lead to serious errors if the pattern and character of groups at the three stations are not taken into account.

Velocity determinations for microseisms are open to question when they are based on records from horizontal-component seismographs only, which do not permit distinguishing between Rayleigh and Q waves.

HISTORICAL INFERENCES FROM A RECENT EXPOSURE OF THE HAYWARDS FAULT NEAR NILES, CALIFORNIA

George D. Louderback
University of California, Berkeley, Calif.

Recent excavation has exposed the Haywards fault in the Niles Cone of Alameda Creek. The phenomena observed there are compared with those seen in bedrock sections of the fault, and it is concluded that they represent only a very recent part of the active life of the fault. The explanation offered is based on the late development and modification of that portion of the Niles Cone in which these phenomena are exposed at present.

HISTORY OF THE SEISMOLOGICAL STATION AT FRESNO, CALIFORNIA

V. Calvon McKim
Fresno State College, Fresno, Calif.

Seismology at Fresno may be classified in two stages: observational and scientific. "Felt" quakes were recorded by the Weather Bureau from 1892–1935. Dr. Perry Byerly, in co-operation with Dr. William M. Tucker, set up the first station on November 28, 1935. The seismometer consisted of a Wood-Anderson from this date until October 14, 1947, at which time a three-component Sprengnether was installed.

Both piers have been insulated against vibrations from the sub-basement floor and were anchored on a substantial layer of hardpan in the San Joaquin Valley alluvium, at 30–50 feet above ground-water level. The station is located at 36°45′ N. lat. and 120°15′ W. long., at about 292 feet above sea level. The following section is taken from a report of tests made by the U. S. Coast and Geodetic Survey in the winter of 1948: "the synchronous magnification of the N.-S. component instrument is about 6000; that of the E-W about 5000; and that of the vertical about 8500. The free periods of the seismometers and the galvanometers are about 1.9 seconds. The damping is near critical." The station is now in the charge of the Head of the Department of Geography and Geology, Fresno State College, Fresno, California.

In the annual summary published by the University of California 1418 distinct temblors have been noted. Prior to the establishment of the station, 21 "felt" quakes had been recorded by the Weather Bureau. It is evident in the reports that the station is performing its regional function as a contributor to the details of seismic disturbances in the California section of the "Pacific Circle of Fire."

AIRY PHASE OF SHALLOW-FOCUS SUBMARINE EARTHQUAKES

Frank Press, Maurice Ewing, and Ivan Tolstoy
Columbia University, New York, N. Y.

An extension of the theoretical work of Lamb and Pekeris shows that a prominent phase (Airy phase) consisting of a group of waves of period 9–11 seconds, travelling across the ocean with a velocity of approximately 0.7 of the speed of sound in water, should be present on the seismograms of shallow-focus submarine earthquakes. This arrival corresponds to normal-mode propagation at a stationary value of group velocity through the acoustic system consisting of the ocean and the rigid ocean bottom.

A phase fitting this description has been observed on the Milne-Shaw instruments at Bermuda for a series of Dominican Republic shocks. The Wenner seismographs at Huancayo recorded the Airy phase of a shock southwest of the Galapagos Islands.

The study of the Airy phase of a sufficient number of sea quakes would provide information concerning the nature of the ocean bottom since the latter affects both the periods and velocities of the Airy phase.

DESERT HOT SPRINGS EARTHQUAKE OF DECEMBER 4, 1948

C. F. Richter
Seismological Laboratory, 220 N. San Rafael Ave., Pasadena, Calif.

Preliminary elements for this shock are: epicenter 33° 55′ N. 116° 28′ W., origin time 15:43:17 Pacific Standard Time, magnitude about 6.6–6.7. Damage, chiefly minor, occurred in Palm Springs, Indio, and Desert Hot Springs. Near the Indio Hills horses and children were thrown off their feet. Aftershocks were recorded with a portable seismometer at several locations near the epicenter, and a temporary station was set up for continuous recording at Desert Hot Springs. Seismograms from the nearer points show an apparent S-P of 1.5 seconds or less which seems too short. This has been observed near the epicenters of other shocks and is as yet unexplained.

SEISMOLOGICAL ACTIVITIES OF THE U. S. COAST AND GEODETIC SURVEY DURING 1948

Elliott B. Roberts
U. S. Coast and Geodetic Survey, Washington, D. C.

The Survey continued its regular program of collecting and reporting information on earthquakes felt in the United States, analyzing the records of 27 seismological observatories and 56 strong-motion stations, vibration studies, co-operation with other organizations in installing equipment, and its program of limited research chiefly on microseisms and travel times of elastic waves. In addition to the regular program, the Survey announced inauguration of a seismic sea wave warning service in the Pacific and the expansion of the program for the preliminary determination of epicenters to provide world-wide coverage of strong shocks. A Seismic Probability Map of the United States based on the history of destructive shocks was issued. Sound waves travelling through water were identified on the records of submarine shocks in the Aleutians and elsewhere. Progress was made on a new method of calibrating electromagnetic seismographs.

In western United States 2460 reports of 208 earthquakes were received. Forty-three earthquakes of intensity V or greater occurred during the year; the maximum intensity of VII was observed in three earthquakes during December. Accelerographs were installed at Golden Gate Park in San Francisco, Taft, and San Luis Obispo, California, and Olympia and Seattle, Washington. A Weed strong-motion seismograph was installed at Monterey. Ninety-three unifilar suspensions were installed, completing installation of unifilars in all United States instruments. Sixty-six strong-motion records of 21 shocks were obtained during the year.

METHOD OF OBTAINING A TRAVEL-TIME CURVE WITHIN A STRIPPED EARTH

V. C. Stechschulte, S.J.
Xavier University, Cincinnati, Ohio

A simple method is outlined for obtaining from a time-distance curve of a deep-focus earthquake a table of travel times within an earth "stripped" to the depth h, the depth of focus. The method depends on the fact that such a curve for a deep-focus earthquake has a point of inflection and therefore has the same slope at two different values of epicentral distance. The Herglotz-Wiechert method may then be applied to these travel times to obtain a velocity-depth distribution.

"T" PHASE OF SHALLOW-FOCUS SUBMARINE EARTHQUAKES

Ivan Tolstoy, Maurice Ewing, and Frank Press
Columbia University, New York, N. Y.

A short-period phase, 0.5 sec. period or less, travelling through the ocean with the velocity of sound in water has been identified on a large number of seismograms of earthquakes occurring at sea. This arrival was identified on the Benioff short-period seismograms of the Weston, Fordham, and Ottawa stations for a series of Dominican Republic shocks, and on the Benioff short-period seismograms of the Pasadena network of stations, the Mt. Hamilton and Mineral stations for a series of major Japanese and Aleutian shocks.

The existence of this phase had been noted previously by Linehan who was at a loss to explain them. The mechanism of propagation of the "T" phase is discussed, and several practical applications are described.

KERN CANYON FAULT, KERN COUNTY, CALIFORNIA*

Ray C. Treasher
3932 12th Ave., Sacramento, Calif.

The Kern Canyon fault heads in the area southwest of Mt. Whitney and continues southward to Bodfish roughly parallel to the Kern River. The fault continues southward into Havilah Valley and

*Published by permission of the District Engineer, Sacramento District, Corps of Engineers.

possibily as far as Caliente. It has been traced for 80 miles. In the present study, the geology of the Isabella quadrangle was mapped, and the fault pattern was studied in detail. The Kern Canyon fault has a northerly strike. North of Bodfish it is a high-angle thrust fault with a westerly dip. South of Bodfish it is a high-angle normal fault with an eastward dip. The Cook Peak fault splits from the main fault north of Kernville as its east branch and continues southward to Erskine Creek on the east side of Cook Peak. The Tillie and Erskine faults parallel the creeks of the same names with a generalized N. 45° W. strike and dip steeply or are vertical. Several minor faults are mapped. Evidence of recent activity along the Kern Canyon and associated faults is contradictory. There is, however, a significant grouping of epicenters along the fault north of Kernville.

ELECTRONIC SEISMOGRAPH

Joseph A. Volk and Florence Robertson
Institute of Technology, St. Louis University, St. Louis, Mo.

Satisfactory recordings of microseisms make the availability of a highly sensitive seismograph a prerequisite. While electronic amplification is a logical means of obtaining the desired results, the DC amplifier commonly used for amplifying very low-frequency amplitudes lacks sufficient stability. By the use of a high-frequency carrier (8.6 mc.) the problem of obtaining the required sensitivity together with a high degree of stability is solved in a most satisfactory way. The various components consisting of the Capacity Bridge Seismometer, its RF Generator, the high-frequency Amplifier and Detector as well as various power supplies are fully described. A new type of timing unit, tuning-fork controlled, is also outlined. Actual recording of half-second microseisms are shown.

REPORT OF FIELD INVESTIGATION OF COACHELLA VALLEY EARTHQUAKE ON DECEMBER 4, 1948

S. E. Warner
U. S. Coast and Geodetic Survey, San Francisco, Calif.

This earthquake, felt throughout Southern California, Southern Nevada, and Western Arizona, reached Intensity VII (Modified Mercalli scale) at the epicentral region in the foothills near Palm Springs, California, and is attributed to movement on the Mission Creek fault.

Minor damage, confined chiefly to broken glass and cracked masonry, occurred in the upper Coachella Valley and surrounding hills, an area of low population and limited building construction. Few injuries were reported, and several interruptions in electric service occurred.

In the metropolitan area of Los Angeles, the shock was widely felt, but damage was limited to some thin masonry sections and a few instances of broken glass. Earthquake shutoff valves installed on gas service lines operated in some locations. No injuries were reported, and public-utilities services were not affected in this area.

Landslides and dust clouds were reported in the foothills around the epicentral area in the loose surface material characteristic of this area. In other places, the ground was cracked, springs increased their flow, and walls were affected.

ABSTRACTS OF PAPERS PRESENTED AT MEETING IN BOULDER, APRIL 23, 1949

ROCKY MOUNTAIN SECTION OF THE GEOLOGICAL SOCIETY OF AMERICA

CAMBRIAN STRATIGRAPHY OF THE SOUTHERN FRONT RANGE, COLORADO

Richard V. Addy

Colorado Springs, Colorado

Detailed study of the Sawatch sandstone of the Southern Front Range of Colorado has resulted in closer correlations with the Sawatch quartzite members established by Johnson in central Colorado. Three members are recognized—the Lower sandstone member, Glauconitic sandstone member, and Peerless shale member.

The basal contact with the Precambrian rocks is sharp. The contact with the overlying Manitou limestone and the contacts between the members are gradational. Fossils are scarce and poorly preserved, and most of the correlations are based on similarities of lithologic sequences.

Depositional features indicate that the sands were deposited in a shallow sea transgressing eastward over an extensive base-leveled surface. Structural relations and lateral variations in thickness suggest a continuous seaway across Colorado in late Cambrian time with positive, oscillating land masses in the northern and southern parts of the State.

PERIDOTITE BODY IN THE LARAMIE MOUNTAINS, WYOMING

John Albanese

Laramie, Wyoming

A lenticular peridotite body 2½ miles long and ½ mile wide is located on the east flank of the Laramie Mountains 25 miles northwest of Wheatland, Wyoming.

The peridotite body lies within a region of Precambrian gneisses and hornblende schists. Hornblende schists occur as narrow tabular bodies within gneiss.

The peridotite occurs within the core of a tightly folded plunging syncline. The horizontal projection of the synclinal axis strikes N. 20°E. The synclinal axis plunges 45° S.W. The core of the peridotite is a coarse-grained rock composed of diallage (55%) and olivine (35%). The core is surrounded by a rim of coarse-grained bronzite-peridotite (bronzite 50%, diallage 25%, olivine 20%). Hornblendite (95% actinolite) occurs along the northwestern margin and constitutes the southern extremity of the body. Serpentinization is very limited. Lineation is very well developed at places within the peridotite. Biotitic quartz monzonite gneiss encloses the peridotite. The contact is sharp and conformable.

Regional strike of gneissic foliation is N. 20° E. Adjacent to the peridotite, strike of gneiss follows the outline of the peridotite body. Dip of gneissic foliation is inward toward the synclinal peridotite body and ranges from 55° to vertical. Direction of plunge of both lineation and drag fold axes within gneiss is generally parallel to regional strike of gneissic foliation and plunges 45° S.W.

Field and laboratory evidence suggests that gneiss formed by metasomatic replacement of hornblende schist along pre-existing structure at temperatures and pressures characteristic of the amphibolite facies.

GEOLOGY OF THE NORTHERN PART OF THE SANGRE DE CRISTO MOUNTAINS, COLO.

Charles R. Butler

Boulder, Colorado

The Sangre de Cristo Mountains extend from central New Mexico into south-central Colorado. The area described is south of Salida, Colorado, and includes the extreme northern end of the range between the Arkansas River and the San Luis Valley.

Sediments range in age from Cambrian to Permian (?) and are correlated with type sections at Leadville and Kerber Creek. A section near Bushnell Ridge shows the following sequence: Manitou limestone, 150 feet, Harding quartzite, 60 feet, and Fremont limestone, 200 feet, all of Ordovician age; Dyer dolomite, 172 feet, of Devonian age, and Leadville limestone, 100 feet plus, of Mississippian age. Permo-Pennsylvanian red beds cover a large part of the area. The Ordovician and Devonian sediments contain several felsite porphyry sills from 1 to 50 feet thick. Much of the bedrock is concealed by glacial debris.

Tightly compressed folds and faults characterize the highland structure. Precambrian metamorphics and granites are exposed at the crest of the range. A horst of Precambrian rock, a mile wide, extends southward from Bushnell Ridge for at least 4 miles, parallel to the trend of the range.

Sulfide replacement deposits of tetrahedrite, sphalerite, and galena occur in minor amounts in the pre-Pennsylvanian limestones and dolomites.

COAL CREEK QUARTZITE, JEFFERSON AND BOULDER COUNTIES, COLORADO

George D. Fraser

Boulder, Colorado

The Precambrian Coal Creek quartzite crops out in a triangular area 7 miles long and up to 3 miles wide near the mouth of Coal Creek Canyon, Jefferson and Boulder counties, Colorado. A major synclinal in the quartzite body plunges northeast, but Tertiary and Precambrian faults locally rotate axial rods of drag folds so that they plunge steeply southwest. Most of the lineation is of the fold-axis type and consists of elongate quartz rods in a schistose matrix. Tension fractures at right angles to maximum stretching are conspicuous.

Fine-grained quartz-muscovite-biotite schist interbedded with the quartzite contains a few garnet crystals and, locally, abundant cordierite, especially in the synclinal trough. The presence of cordierite, an anti-stress mineral, in a highly crenulated schist can be explained only if it is younger than the major deformation. Cordierite and associated microscopic blue-green tourmaline are believed to be the result of pegmatitic invasion which followed diastrophism.

Age relationships are obscure because contacts between quartzite and Idaho Springs formation are fault contacts. It is believed that the Coal Creek quartzite is younger than the Idaho Springs formation, and older than some of the granite. Pegmatites and granites impregnate portions of the schistose layers in the quartzite, and pegmatites are intruded along a definite Precambrian fault zone marking the southeast boundary of the quartzite mass.

Marked lithologic difference between the Idaho Springs formation and the Coal Creek quartzite suggests a sedimentary break of some magnitude, but no evidence of a major angular unconformity was found.

LARAMIDE STRUCTURE AND IGNEOUS ACTIVITY OF THE FULFORD AND BRUSH CREEK MINING DISTRICTS, COLORADO

John W. Gabelman

Colorado School of Mines, Golden, Colorado

The Laramide structure in the Fulford and Brush Creek mining districts, of the northwestern Sawatch Range, is complex. Structural features are divided into a northeast system, an east-west system, and a combination of the two. The northeast structures consist of four thrust faults, a large basin, and related smaller folds; they are the result of southeastwardly directed pressure attendant to the main uplift of the Sawatch massif. The east-west structures consist of monoclinal northerly dips and high-angle faults of large displacement believed caused by the uplift of a large anticline in Frying Pan Creek. The resultant forces in the area of intersection produced combined structures and a northwest-trending narrow zone of weakness, along which intrusives and ore deposits were introduced. A small stock near Fulford wholly in sediments has a minimum of contact phenomena, but shows internal differentiation from quartz diorite through granodiorite to quartz monzonite porphyry. Granite pegmatite in fractures cuts the stock. Hydrothermal alterations are intense within the stock, but almost nonexistent in the confining rocks. Numerous sills of late quartz monzonite porphyry are found close to the stock, and echelon dikes of the same extend southeast along the zone of weakness.

Several small dikes and pipes of andesite porphyry are at the southeast end of this zone. The final igneous action was the outpouring of basalt from vertical vents north of the stock.

ZONATION AND CORRELATION OF THE PIERRE SHALE OF COLORADO

Mary O. Griffitts

University of Colorado, Boulder, Colorado

The Pierre shale, basal formation of the Montana group in Colorado, ranges in thickness from less than 1000 feet in the southeastern part of the State to approximately 8000 feet in the northern foothills. On the basis of lithologic and faunal characteristics the Pierre of northeastern Colorado is subdivided into four zones, from the base upward: the Sharon Springs shale zone, the Rusty zone, the Hygiene zone, and the Transition zone. Five units are locally recognized within the Hygiene member, and three of these are persistant over much of Colorado. The Pierre zones are traced throughout eastern and central Colorado, and tentative correlations are suggested with the Mancos and Mesaverde formations of western Colorado.

The problem of the origin of the Hygiene member is discussed. Regional lithologic studies indicate the possibility of a local origin of this sandstone tongue.

SIMPLE METHOD OF PREPARING CRYSTAL MODELS

A. J. Gude

Golden, Colorado

Satisfactory models for use in the study of crystallographic morphology have for years been difficult to obtain. A method of preparing models from stiff paper cutouts has been evolved which satisfies most requirements. Every unique form in all the systems is included. Combined forms are developed only where it is necessary to close a model. The relationship among forms in a class and among classes in a system can be shown on uncombined forms. Each student may be provided with a construction kit. Thus, the laboratory work may be supplemented with homework involving the preparation of paper models for future reference.

The method of preparing the drawings is demonstrated, and several typical assembled paper models are shown.

GEOLOGY OF WHISKEY GAP-MUDDY GAP AND FERRIS MOUNTAINS REGION, WYOMING

E. L. Heisey, D. E. Lawson, and R. J. Weimer

Laramie, Wyoming

The geology of a 209-square-mile area, of the Ferris Mountains and adjacent region, in Carbon and Fremont counties, Wyoming, is presented. The discussion represents the composite geology of three adjoining thesis areas. Included with the report are detailed geologic maps and structure sections.

Strata representing all geologic periods except Ordovician, Silurian, and Devonian are present. Detailed sections were measured in two localities.

The Ferris Mountains are a sharply folded doubly plunging anticline, trending N. 75° W., with an adjacent tightly folded syncline to the north. The geologic structure is divided into western, central, and eastern divisions for this presentation. In the western division, a north-dipping low-angle thrust, called the Whisky Gap thrust, is present. East of U. S. Highway 287 overturned Paleozoic rocks are present in the thrust sheet. West of this highway, the thrust sheet contains granite which rests progressively on younger sediments. In the central division, the Ferris Mountain anticline is overturned and thrust to the north. Precambrian rocks are in fault contact with lower Paleozoic rocks. An inferred outlier of the Whiskey Gap thrust rests on Precambrian in the northern part of the area. In the eastern division, there is a north-dipping thrust which is a probable extension of the Seminoe thrust. This thrust places Precambrian on overturned Cambrian strata. Three northward dipping normal faults which trend northwest are present.

GEOLOGY OF THE WEST SIDE OF THE GORE RANGE NEAR RADIUM, COLORADO

Olcott Gates

Boulder, Colorado

An area near Radium, Colorado, on the Colorado River about 6 miles west of the Gore Range was mapped to determine the western limit of the Ancestral Rockies and the nature of Laramide movements on the west side of the Gore Range.

The Radium area is on the west flank of the Ancestral Rockies. Erosion was active on Precambrian rocks not far to the east probably as late as early Upper Triassic. Pennsylvanian sediments wedge out abruptly against Precambrian rocks. Permian formations are apparently absent. A coarse angular conglomeratic graywacke rests on the Pennsylvanian sediments to the west and on Precambrian rocks to the east. The graywacke is probably of early Upper Triassic age and is derived from near-by Precambrian metamorphic and igneous rocks.

The Laramide structures include: (1) southeast-plunging faulted anticlines, whose eroded Precambrian cores form high ridges that dissect the sediments; (2) nearly vertical normal faults which strike eastward; (3) a thrust fault which is the dominant structural feature. The thrust fault crosses the eastern part of the Radium area, strikes northward, and dips eastward. Differences in stratigraphy east and west of the fault show that a block was thrust westward probably several miles. The block consists of Precambrian rocks from which the graywacke was derived and of Upper Triassic and Jurassic formations considerably thinner than those to the west. The thrust fault suggests that the Gore Range was thrust westward during Laramide movements. It is probably a western branch of other similar faults along the western side of the Gore Range.

STRATIGRAPHIC AND MICROPALEONTOLOGIC ANALYSIS OF THE MAQFI SECTION, FARAFRA OASIS, WESTERN DESERT OF EGYPT

L. W. LeRoy

Colorado School of Mines, Golden, Colorado

Thirty-three species of Foraminifera from the Upper Cretaceous and 100 species from the Lower Tertiary of the Maqfi section, Farafra Oasis, Egypt, are recorded. Twenty-seven species are considered new. The results of this analysis should serve as control for future micropaleontologic and stratigraphic investigations of the Western Desert.

Deposits comprising the Maqfi section involve two Upper Cretaceous units (B and A) and three Lower Tertiary units (3, 2, 1). The lowest Cretaceous strata (Unit B, Maestrichtian) consist of +150 feet of white, massive chalk and chalky limestone in which *Globotruncana* and *Gumbelina* are prolific. The uppermost Cretaceous deposits (Unit A, Danian?) attain a thickness of 72 feet, consist of medium-gray, moderately bedded, calcareous shale to impure limestone, and are typified by the foraminifer *Globorotalia velascoensis*. This unit is separated from the overlying Lower Tertiary (Unit 3) by a marked erosional surface. Its lower boundary also is believed to involve disconformable relationships with Unit B.

The lowermost Tertiary strata (Unit 3) of the section consist of 7 feet of hard, gray foraminiferal limestone containing numerous *Operculina libyca* and *Nummulites deserti*. These deposits are unconformably overlain by the Esna (Unit 2) which comprises 433 feet of soft, fissile, gray-green, highly foraminiferal shale. The shale grades upward into massive- to thick-bedded, buff, escarpment-forming limestones of Unit 1 characterized by an abundance of small *Nummulites*, *Flosculina*, and *Operculina*, and a well-developed molluscan fauna.

In this paper, distribution and development of the small Foraminifera of the Esna shale are emphasized; moderate consideration is given the Cretaceous microfaunas. The large Foraminifera (*Flosculina* and *Nummulites*) occurring in the section are not systematically treated.

The microfaunal subdivisions of the Esna shale as herein defined should not be considered as possessing zonal value until additional regional investigations have been made.

GEOLOGY OF THE BRIGHT ANGEL QUADRANGLE, ARIZONA

John H. Maxson

1585 Kearney Street, Denver, Colorado

Historical Geology

The depositional, orogenic, and erosional history of the Bright Angel quadrangle may be given in outline form.

Quaternary:	Canyon-cutting		
Tertiary:	Late	Epeirogenic uplift of Colorado plateau.	
	Early	Recurrence of faulting; flexing of Mesozoic and Paleozoic strata, gradual uplift and stripping of Mesozoic strata.	
Mesozoic:	Post-Moenkopi rocks deposited but removed by Tertiary stripping.		
	Triassic	Moenkopi formation (50 feet remaining in one locality).	
Paleozoic:	Permian	Kaibab limestone	380 feet
		Toroweap formation	280 feet
		Coconino sandstone	300 feet
		Hermit shale	340 feet
		Supai formation	1100 feet
	Mississippian	Redwall limestone	700 feet
	Devonian	Temple Butte limestone	0–100 feet
	Cambrian	Muav limestone	500 feet
		Bright Angel shale	400 feet
		Tapeats sandstone	0–300 feet
Ep-Algonkian:	Erosion to senesland.		
	Grand Canyon Revolution—Block faulting.		
Algonkian:	Grand Canyon series.		
	Chuar Group (removed during Ep-Algonkian erosion)		
	Unkar Group-Dox sandstone, including diabase sills (upper part removed by Ep-Algonkian erosion)		2500 feet
	Shinumo quartzite		1500 feet
	Hakatai shale (with diabase sills)		600 feet
	Bass limestone		250 feet
Ep-Archean:	Erosion to peneplain		
	Arizonan Revolution—Orogenic deformation, regional metamorphism, intrution of Zoroaster granite batholith, extensive granitization and pegmatization.		
Archean:	Vishnu paraschists		

Now	Originally
Quartz mica schists	Argillaceus sandstones and arenaceous shales
Quartzites	Well-sorted quartz sandstones
Ferruginous quartzites	"Iron formations"
Garnetiferous quartz mica schists	Limey, arenaceous shales
Calcareous concretionary schists	Limey, arenaceous shales
——	Metabasites
Amphibolite schists	Basalts

Structural Development

A fault pattern was early established which influenced the pattern of recurrent displacements. Periods of faulting may be summarized:

1. Archean faulting
   Fault zones injected by pegmatite or cemented by quartz. Northeast and northwest criss-cross in pattern.
2. Ep-Archean faulting
   Fractured Archean basement overlain by undisturbed Bass limestone. Extent of faulting unknown.
3. Algonkian faulting
   Fault planes cutting lower Algonkian strata injection by diabase of middle Algonkian age.
4. Ep-Algonkian faulting
   Blocks of Algonkian strata were inset in Archean basement on subparallel northwest striking steep-angle normal faults, including the Hindu fault in Hindu amphitheater, the Phantom-Cremation fault, and the Ottoman fault in Ottoman amphitheater. Most important of the northeast-striking system was the α Bright Angel fault, on which movement was reverse and oblique slip. Dip-slip component was at least 500 feet and probably more than 1000 feet. Strike-slip component was as much as 2000 feet with northwest block moving relatively northeast. α Bright Angel fault itself was displaced by movement on the northwest system near the Colorado River.
5. Early Tertiary faulting
   Reverse movement of 100–200 feet occurred on the northwest-striking Ep-Algonkian faults, causing fault displacement in Tapeats sandstone and monoclinal folding of Paleozoic section above. Normal faulting occurred on β Bright Angel fault whose trace is close and nearly parallel to α Bright Angel fault. Stresses required for these movements were applied at 90° to their Ep-Algonkian alignment. Brecciated zones in the Paleozoic mantle, caused by small dip-slip and strike-slip displacements extending upward from the Ep-Algonkian system, have guided Grand Canyon erosion in plan detail.

MATERIALS FOR POZZOLAN

R. C. Mielenz, K. T. Greene, N. C. Schieltz, and M. E. King

Bureau of Reclamation, Denver Federal Center, Denver, Colorado

Interest in pozzolans for use in concrete is increasing to such an extent that it behooves the geologist to learn their properties and identity. Pozzolans are siliceous and aluminous materials which react with lime at ordinary temperatures producing cementitious compounds.

Natural pozzolanic materials can be identified by petrographic methods. Effective volcanic ashes are rhyolitic, dacitic, andesitic, or phonolitic. Clayey materials may contain laolinite, montmorillonite-type minerals, illite (hydromica), or palygorskite; clayey pozzolans require calcination to activate the clay and reduce water requirement. Opaline pozzolans include diatomaceous earth, siliceous shales, and some cherts. Diatomaceous earth is the most active of natural pozzolans, but its use ordinarily increases water requirement and hence drying shrinkage of mortar and concrete. Industrial by-products include fly-ash, ground brick, and blast-furnace slag.

Investigations of pozzolans are being conducted by many organizations in the United States. When used to replace a portion of the portland cement in concrete, many satisfactory pozzolans will decrease costs; reduce heat of hydration; increase workability; decrease water gain and segregation; increase resistance to aggressive waters; and increase tensile strength, usually without critical loss in strength or durability. Less satisfactory pozzolans introduce adverse properties to the concrete. Some pozzolans will prevent or greatly retard the interaction of cement alkalies and aggregates, a process sometimes causing intense deterioration of concrete.

Natural pozzolans which control alkali-aggregate reaction in concrete include: opaline materials; calcined kaolinite, certain montmorillonite-type minerals, and palygorskite; and certain rhyolite pumicites. These pozzolans are the most valuable.

PENNSYLVANIAN STRATIGRAPHY OF THE McCOY AREA, COLORADO

Harrison F. Murray

Boulder, Colorado

The 2960-foot interval of sediments between the top of the Madison limestone and the bottom of the Phosphoria formation in the vicinity of McCoy, Colorado, is assigned to the Permo-Pennsylvanian without definition of the boundary between the two periods. Eighty-five per cent of the section is fluvial arkosic conglomerate. The remaining 15 per cent is cross-bedded sandstone and fossiliferous marine shale and limestone. Four zones are recognized. The lower 540 feet is composed of friable arkosic sandstone and conglomerate without evidence of marine deposition. The middle zone consists of 1280 feet of red arkosic conglomerate with interbedded red to black micaceous shale, cross-bedded sandstone, and thin fossiliferous marine limestones. The third zone of 1070 feet of resistant red arkosic conglomerate contains no evidence of marine deposition. The beds directly below the Phosphoria are 59 feet of dark-gray cross-bedded sandstones which are correlated with the Schoolhouse sandstone of northwestern Colorado.

The stratigraphic interval between the bottom of the red siltstones of the Phosphoria formation and the top of the highest Pennsylvanian limestone is 1100 feet in the NE ¼ sec. 9, T. 2 S., R. 84 W., but 3 miles east, in the NE ¼ sec. 25, T. 1. S., R. 84 W., this same interval is only 200 feet, and the Schoolhouse sandstone is not present. This is indicative of a post-Schoolhouse, pre-Phosphoria erosion surface with possible angular unconformity on the flanks of the Ancestral Rockies.

RELATION OF STRUCTURE TO PETROLOGY IN THE NORTHERN BIGHORN MOUNTAINS, WYOMING

Frank W. Osterwald

University of Wyoming, Laramie, Wyoming

The Precambrian core of the Bighorn Mountains, west of Sheridan, Wyoming, consists of a series of red and gray granitic rocks. Granites are of uniform mineralogy but present a wide variety of textural types. Remnants of older rocks are rare; inclusions of dark biotitic rocks are found in scattered localities. Petrologic study suggests that metasomatic processes have been important in the formation of the granitic rocks. Metasomatism was most intense where deformation was greatest.

A large syncline in the granitic rocks occurs west of South Tongue River and plunges north-northwest. Granites in the core of the syncline are massive; more gneissic types are found on the flanks. Eastward from the syncline, foliation in granites is more pronounced, has flatter dip, and forms a series of gentle, open folds. Near North Tongue River, and at other localities, dark-green sheared rocks occur in outcrops which trend east-northeast, or north-northwest.

Flat-lying early Paleozoic sediments occur along the western and northern margins of the area. Contact between Paleozoic and crystalline rocks is flat and corresponds generally to the level upland surface of the mountains. Locally isolated patches of Cambrian sandstone and of Oligocene beds are found upon the stripped surface.

The combination of a rectangular fracture pattern in crystalline rocks, and the horizontal attitude of a Precambrian erosion surface suggests that the Bighorns in this area originated by vertical block movements in granitic rocks. Marginal structures produced during Laramide deformation are related to these block movements.

LITHOFACIES PROBLEMS, NEWCASTLE SANDSTONE, MUSH CREEK AND SKULL CREEK AREA, WESTON COUNTY, WYOMING

H. E. Summerford, E. E. Schieck, and T. C. Hiestand

Casper, Wyoming

Problems of accumulation of oil and gas in the Newcastle sandstone (Upper Cretaceous) involve facies changes from shale to sandstone which are recognized most clearly in the Mush Creek and

Skull Creek area. Well sample and electric log information from 200 wells in the area has afforded details to classify five sand beds which underlie the datum bed at the top of the Newcastle sandstone. The structure on outcrops and on the subsurface datum bed is a monoclinal southwest dip of approximately 2°, formed post-Cretaceous time, Laramide orogeny. The type log describes the lithology of the five sand beds and shale interbeds. Cross sections and lithofacies maps of the respective sand beds illustrate the facies changes in the Newcastle sandstone. The accumulation of oil in the area is directly related to the porosity, permeability, and thickness of each sand bed. The post-Cretaceous monoclinal southwest dip on the Newcastle sandstone does not form a structural trap and does not appear to have caused any appreciable migration of the oil in the respective sand beds. The oil accumulation is closely related to the local stratigraphic and geographic site of the origin of the oil. Recognition of lithofacies changes in the Newcastle sandstone now has been widely accepted and is being utilized in a broad exploratory program.

NOTES ON PERMAFROST PROBLEMS IN CONSTRUCTION ENGINEERING

Daniel S. Turner

University of Wyoming, Laramie, Wyoming

An understanding of the complex engineering problems inherent in an area of permafrost is essential to successful construction operations in Arctic regions.

With the mounting interest in Arctic investigations, for both military and economic purposes, a study of frozen ground problems by American geologists is certainly of particular importance. Many of the commonly simple procedures of construction are seriously complicated by the characteristics of a perpetually frozen ground. Removal of the insulating blanket of vegetation, in preparation for grading operations, causes thawing of the upper soil horizon during the summer months. Drainage problems become complex, both in the construction of ditches and in surficial runoff. Bridge footings cause a serious disturbance of permafrost, which proved disastrous to completed structures. Building foundations warm and thaw the underlying soil, introducing another problem peculiar to the Arctic regions. The laying of water mains and sewage systems becomes a complex problem, where they cannot be buried below a "frost line". The solution of the foregoing problems confronted many of the wartime construction units which built bases in the Arctic during the war. Many of these operations were seriously impeded, during critical months of the war, largely because of the lack of a knowledge of the geological problems involved with permafrost. The lack of experience and information on permafrost forced costly airfield relocations, loss of precious time, and in some cases complete loss of structures.

A brief report of observations and the handling of some of these problems will be presented with lantern slide illustration.

ABSTRACTS OF PAPERS PRESENTED AT MEETING OF SECTION E (Geology and Geography)

In New York, December 29 and 30, 1949

DRAINAGE PATTERNS

Charles W. Carlston

Oberlin College, Oberlin, Ohio

Although the Zernitz classification of drainage patterns, published in 1932, provided information of basic importance to the geologist, most textbooks of physical geology and geomorphology published since that date discuss only two or three of the patterns. Some texts have ignored the subject, and some have made errors in their presentation of drainage patterns.

This may be due in part to the Zernitz classification which is illogically arranged and which recognizes too many types of patterns. A few of the patterns are poorly named. The present paper reduces Zernitz' 16 patterns to a more coherent whole, reclassifies the patterns, and clarifies the naming and description of some of the patterns.

GLACIAL MOLDING OF THE GULF OF MAINE

George H. Chadwick

Catskill, New York

Revelation of details of the ocean floor in the western deeps of the Gulf of Maine by Murray's (1947) maps and profiles leads to novel interpretations. The bottom ice-flow in the Gulf formed a great eddy crowding around from the Bay of Fundy on the northeast against Boston (Stellwagen Bank) and Cape Cod finally to escape at the southeast by "Northeast Trough" east of George's Bank, though at maximum a tongue also pushed southwest into the shallow notch east of Nantucket Shoals. Ice-eroded "bath-tubs" (dorrs) include the great Wilkinson Basin at west. East of this the areas of (rough) crystalline rocks on north and (smooth) coastal-plain strata on south are easily distinguished; the latter is ridged across by five concentric morainal loops of ice "recession." A third area (less smooth) at northeast may be Triassic as Johnson thought. Platt's Bank and Fippennies "Ledge" are river-and-ice-carved remnants (outliers) of coastal-plain beds but not forming subordinate cuestas as he supposed.

Cashe's Ledge is a submountain range of crystallines forming an imposing monadnock on the Fall Zone peneplain, of which there are several smaller examples. Three Dory Ridge, adjoining the Triassic(?) area, simulates a huge trap dike, while neighboring Jeffrey's Bank, northeast, may be the trap sill of northwest Nova Scotia, extended. In the crystalline area, minor moraines seem lost in the rough surface, or perhaps the ice finally stagnated.

Preserved here, free from subaerial reshaping, we have a surface just as the ice left it.

STATISTICAL TREATMENT OF FACIES CHANGE

Philip A. Chenoweth

Amherst College, Amherst, Mass.

The middle Trentonian Kirkfield, Shoreham, and Denmark limestones of northwestern New York have been studied with emphasis on lithic details. Statistical treatment of the data brings out relationships not obvious in normal procedures and enables more precise statements of the quantities. Regression lines have been used in an analysis of facies changes. The standard errors of estimate and the T-tests of the regression coefficients show the value and reliability of the lines. Thus the Shoreham and Denmark formations are shown to become progressively and significantly more argillaceous to the southeast. The techniques involved, and the advantages and limitations of such a study are summarized.

SPONTANEOUS GROWTH OF RADIALLY CONSTRUCTED CRYSTAL AGGREGATES FROM SUPERCOOLED MELTS

(A New Hypothesis Regarding Origin of the Moon's Surface Features)

Karl H. Engel

1310 Princeton Road, West Englewood, N. J.

Radial structures of essentially two-dimensional symmetry emerged from shallow melts of suitable organic substances each of which followed consistently recognizable aggregational habits.

Simplest and most common is the horizontal segment of a radiating star, initiated either at the bottom or in the surface of the liquid. Growth proceeds most commonly within the original liquid. Occasionally, the structure may rise above the surface through liquid creep and by normal extension of crystal growth. The star may become a hemispheric dome or cone.

Unusual developments were displayed by a few substances. They grew normally below the surface. On emergence, crystals sprouted spontaneously in rapidly growing bundles, forming fibrous tufts or complexly woven tubules. These were the new intermediate units of radial shields, pitted mounds, or cuplike structures capable of attaining appreciable size.

A surprising structure emerged from one substance when modified by traces of common organic solvents. Solidification began normally, generally with a submerged cone. Minute detached crystals formed in a liquid mantle surrounding the cone. At a given stage these were swept away by surface convection currents until arrested in a circular halo. The halo served as the start of a new growth that competed against the parent structure and later drew substance outside its rim. Depending on conditions, a great variety of annular growths bore unmistakable structural resemblance to the different types of lunar features ranging from the tiniest mounds and craters to the large maria.

Aggregational habits observable on a scale of 10 to 50 centimeters were repeated with remarkable fidelity in droplets a few millimeters across. Conceivably the same habits, somewhat coarsened, may be preserved on a very large or even planetary scale.

The many formal parallels provided by experimental relief structures support a hypothesis that the surface features of the moon originated through solidification of a relatively shallow layer of supercooled magma.

NATURAL LIMESTONE WALLS OF OKINAWA*

Delos E. Flint

U. S. Geological Survey, Washington, D.C.

Many natural walls of dense, secondarily cemented, cavernous limestone occur on the island of Okinawa as structures resembling natural levees along the banks of streams, as linear ridges along the upthrown edges of fault blocks, as circular walls around old sink holes, and as ridges along the seaward edges of some limestone terraces. In one locality a zone of pinnacles is interpreted as the remnant of formerly continuous walls. These features have been developed in porous, permeable, very poorly cemented, fragmental limestones of the type common in limestone islands of the Pacific. Extensive deposits of residual clay or sandy clay blanket the limestone in the vicinity of the walls.

The author and his associates who worked on Okinawa believe these walls have been formed by secondary cementation of nearly vertical exposures of limestone, followed by differential solution which brought the denser, cemented parts into high relief. The secondary cementation progresses from the surface inward, similar to the "case-hardening" process by which cut blocks of soft limestone harden. Development of a soil cover prevents case hardening in areas removed from steep exposures. Growth of vegetation furnishes organic acids that aid in dissolving the limestone.

*Published by permission of the Director, U. S. Geological Survey.

STRUCTURAL HISTORY OF THE HUDSON VALLEY

Rousseau H. Flower

New York State Museum, Albany, N. Y.

Two contemporaneous series of Cambro-Ordovician strata constitute the Hudson Valley, one dominantly of limestone, the other of shale. Close correlation is possible among the limestone masses which form linear belts separated by shale. Serious discrepancies between the shale and limestone masses indicate different histories of subsidence and elevation requiring their deposition in different regions. Their present juxtaposition is the result of thrusting.

The close correlation between the limestone belts and that of the southern Champlain Valley indicates that they are all part of a single limestone mass which was overridden by the shales. There is no clear evidence of an eastern limestone belt. The limestones are regarded as deposited on the western side of a trough, while shales were deposited to the east in a more rapidly subsiding area, bordered by a land mass which, rising isostatically, supplied materials for the coarse clastics. Uneven sinking and warping of the trough occurred, but in Lower Canadian time simple oscillations caused the western limestones to be periodically eroded, contributing material to the Deepkill conglomerates.

Subsequent tectonic disturbances involve minor foreland thrusts, possibly the result of Taconic movement, and certainly older than the east-west normal faults of the Champlain Valley. Clear evidence exists of post-Taconic faulting, thrusting, and regional eastward metamorphism acted upon a mass already overthrust, and certainly relatively young. Recognition of the Taconic thrust plane is sometimes impossible, where black Trenton shales of the underlying mass lie in contact with similar shales of the Lower Cambrian, both considerably disturbed.

Further complications are caused by the inclusion of limestone masses in the sole of the thrust and their movement westward and sometimes upward into the shale mass. Interpretation of the area in terms of rapidly alternating faciological belts is not tenable.

PETROLOGY OF LOWER ORDOVICIAN CHERTS IN CENTRAL PENNSYLVANIA

Robert L. Folk

Pennsylvania State College, State College, Penna.

Chert nodules are common in the Lower Ordovician Beekmantown Group of Central Pennsylvania. These nodules consist of three varieties of authigenic quartz: (1) microcrystalline quartz, an aggregate of minute grains producing "pin-point" extinction, constitute the great bulk of the cherts; (2) chalcedonic quartz (so-called "chalcedony"), forming radiating bundles of fibers; and (3) normal quartz, forming drusy crystals and, like chalcedonic quartz, occuring in geodes. "Chalcedony" and quartz are mineralogically identical, their observed differences in refractive index being due only to the relative abundance of minute, apparently brownish liquid-filled bubbles in the chalcedony.

The color of chert resembles that of the enclosing carbonate rock. White cherts contain abundant bubbles, and dark-gray cherts contain much organic matter. Internally, the chert nodules may possess any gross structure present in the enclosing limestone. Conglomeratic, fossiliferous, and oölitic bands pass from limestone into the nodule; all structures are perfectly preserved by the chert. Some cherts contain halite molds and geodes; the latter are filled first with chalcedonic quartz and later by normal quartz.

Preservation of clastic limestone structures indicates that the Beekmantown cherts originated by replacement. Cracks in the chert nodules, filled by then unconsolidated limestone ooze from above, prove that replacement was early ("syngenetic"). The chert was jelly-like at the time of formation, shown by wide v-shaped cracks, and brecciation during subaqueous slumping. No evidence of shrinkage upon dehydration was observed. This replacement origin applies to microcrystalline quartz. Chalcedonic and normal quartz have resulted by direct precipitation into cavities.

GEOLOGICAL MAPPING BY THE U. S. GEOLOGICAL SURVEY IN THE GREAT SMOKY MOUNTAINS NATIONAL PARK*

Jarvis B. Hadley

U. S. Geological Survey, National Park Service, Gatlinburg, Tenn.

Since September 1946, P. B. King and J. B. Hadley of the U. S. Geological Survey, and H. W. Ferguson of the Tennessee Division of Geology have been engaged in areal geologic mapping in the Great Smoky Mountains National Park in eastern Tennessee and western North Carolina. Of the twenty-six 7½-minute quadrangles, wholly or partly within the park, about one-fifth have now been mapped on 1:24,000 scale.

Geologic problems concern primarily the stratigraphy, structure, and regional metamorphism of the Ocoee series of late Precambrian (?) age—a mass of clastic rocks of graywacke facies probably more than 25,000 feet thick. This series is a product of rapid erosion, transportation, and deposition in an early eugeosynclinal trough of the Appalachian tectonic belt. The overlying Chilhowee group of Lower Cambrian age, about 3300 feet thick, represents a progressive change from local eugeosynclinal sedimentation to more widespread miogeosynclinal sedimentation on the continental border.

Intrusive rocks of the area consist of a few small bodies of ultrabasic rocks, metadiorite sheets, and synorogenic migmatitic gneiss, all of Paleozoic age. Thrust faulting, folding, and mild regional metamorphism characterize the northern part of the area. A somewhat later stage of folding and greatly increased metamorphism of the Ocoee series are associated with the gneissic intrusives in the southern part of the area.

The cold climates of the Pleistocene have produced thick bouldery solifluction deposits along the teep northern front of the Mountains.

INTERSECTING MINOR RIDGES ON THE LAKE AGASSIZ PLAIN, NORTH DAKOTA

Leland Horberg

University of Chicago, Chicago, Ill.

Low, intersecting ridges, 3 to 10 feet high and 50 to 300 feet wide, with intervening depressions form a fracture pattern which is strikingly revealed on airplane photos. This pattern with modifications occurs over a wide area from Fargo, N. D., north to beyond the Canadian boundary and is particularly well shown in eastern Pembina County, N. D. The ridges are composed of surface soils and underlying laminated lake clays. Coarser constituents are absent.

It is proposed that the ridges may represent frozen-ground structures developed during retreat of the late Wisconsin ice. This is supported by the occurrence of periglacial involutions, plications, and casts of ground-ice wedges in associated coarser, near-shore facies of the lake deposits.

PHYSICAL FEATURES OF VERMONT

Elbridge C. Jacobs

University of Vermont, Burlington, Vt.

The Green Mountains are the dominant physical feature and extend, north to south, from border to border. They are "mature" anticlinoria and synclinoria of schists, gneisses, quartzites, and other metamorphics, intruded by granite and basic rocks. The mountains are a great allochthone which has been thrust northwestward onto the Lowland, along the Mountain Border fault.

The eastern part of the Lowland, composed of Cambrian dolomites and slates, has, as a member of the allochthone, been thrust onto the Ordovician autochthone along the Champlain fault.

The Taconic Mountains occupy the southwest part of Vermont and are also allochthonous. They are made up of several ranges of predominantly slates and carbonate rocks, quite unlike the acid metamorphics to the east and west. The origin of the Taconic rocks is believed to lie far east of the Green Mountains.

---

*Published by permission of the Director, U. S. Geological Survey.

Between the Taconic and Green mountains is the Valley of Vermont, floored in Cambrian dolomite. The Vermont Piedmont extends from the Green Mountains to the Connecticut River. It is a much-dissected peneplain which is an extension of the New England peneplain, of Schooley age. The Northeastern Highlands belong to the White Mountain uplift. The bedrock metamorphics are underlain by great granite batholiths. Vermont Mount Monadnock is a syenite stock. The region is largely a wilderness.

Vermont rivers belong to the Champlain-St. Lawrence, Hudson, and Connecticut systems. Most of the larger streams are super-imposed and have cut their water gaps across the Green and Taconic mountains. Otter "Creek", the longest river in the State, is a subsequent stream.

UPPER DEVONIAN OPHIURANS IN CENTRAL NEW YORK

Robert B. Johnson

Syracuse University, Syracuse, N. Y.

A small colony of ophiurans (ophiuroids) has been discovered in the Upper Devonian Ithaca formation 9 miles south of Cortland, New York. The specimens are impressions of complete animals. None of the specimens has yet been fully classified. All specimens are similar in size and structure. The average overall size is 10 mm. The average diameter of the disk is 3 mm. Each specimen has five unbranched, unintertwined arms. Great variation in the amount of detail exists because of limonite replacement within the shale matrix. Morphology and taxonomy will be discussed. Photographs and line drawings will illustrate the features described.

PLEISTOCENE LAKES IN THE MOHAWK VALLEY, NEW YORK*

Marshall Kay

Columbia University, New York, N. Y.

The theory has been that the Mohawk Valley had a series of extensive postglacial lakes lying west of a retreating ice front and draining over progressively lower outlets in the Helderberg plateau; some contradicting evidence appeared in the mapping of the Utica region for the New York State Museum. The principal varved clays in the area underlie extensive till; they were deposited in lakes preceding the last glacial advance. Younger terminal moraine is present interruptedly along a lobate front west of West Canada Creek from west of Poland to near Herkimer, crossing the Mohawk about at Frankfort toward Frankfort Hill and Norwich Corners. Eskers and other surface glacial features are well preserved westward down to a 600-foot terrace along the Mohawk. Conspicuous wave-cut terraces above 1250 feet on Hasenclever Hill, the east face of the Deerfield Hills west of Middleville, are east of the moraine and at the level of the higher sand plains east of West Canada Creek. Sand plains at about 1000 feet on both sides of the Creek below Poland face lower moraine farther west; wave-cut terraces on Dutch Hill south of the Mohawk are at comparable levels. Lakes receded interruptedly from about 1400 feet to above 600 feet while ice remained over the Deerfield Hills and the plateau south of Utica. Studies in the limited area do not permit judgment of the place and nature of the factors controlling the lake levels.

WISCONSIN GLACIAL STADIA IN NEW JERSEY

Paul MacClintock and L. C. Peltier

Ridge Road, Kingston, N. J.; Washington University, St. Louis, Mo.

Lime has been leached from the Wisconsin drift of New Jersey to various depths. Drift in Northwestern New Jersey shows average of about 5 feet, that of Northeastern New Jersey and Bangor, Pennsylvania, about 12 feet. Delaware Valley outwash terraces near Trenton also show 5 and 12 feet of leaching. The Valley Heads and Binghamton drifts of New York State likewise show leaching of 5 feet and of 12 feet respectively. The drifts of New Jersey may be Tazewell and Cary.

*Published with permission of the Director, New York State Museum.

POSSIBLE NEW GLACIAL SUBSTAGE IN THE MIDDLE ROCKY MOUNTAINS

John Hall Moss

Franklin and Marshall College, Lancaster, Penna.

Detailed mapping of glacial deposits in eight valleys on both the eastern and western slopes of the Continental Divide in the southern Wind River Mountains revealed the presence of a prominent set of moraines upvalley from the massive moraines representing the two pulsations of the Pinedale (late Wisconsin?) substage and downvalley from the smaller moraines attributable to the Neoglaciation. These moraines lying between 10,000 and 11,000 feet altitude are situated ½ to 2 miles from the cirque headwalls. Their frontal portion is commonly 50 to 150 feet high, and from it prominent lateral moraines extend upvalley to the cirques. These moraines are extremely bouldery; however, where finer-grained till is present, a thin topsoil about 4 inches deep and capable of supporting grass has developed. In addition, the till is stained with limonite to a depth of about 10 to 12 inches. In contrast, Pinedale is stained to a depth of 24 to 36 inches, whereas the Neoglaciation till has neither topsoil nor staining. Owing to the size of these moraines and their presence in all valleys studied, they are believed to represent a minor climatic swing to glacial conditions after the Pinedale maxima and before the Neoglaciation. Following Hack's tentative terminology based on reconnaissance studies in one valley, this episode of moraine building is called the Temple Lake Substage.

INVESTIGATIONS IN THE SUBSURFACE GEOLOGY OF THE MARYLAND COASTAL PLAIN

R. M. Overbeck

Johns Hopkins University, Baltimore, Md.

The subsurface geology of the Coastal Plain of Maryland is being studied in the course of an investigation of the ground-water resources of the State by the Department of Geology, Mines, and Water Resources co-operating with the U. S. Geological Survey. Work so far has been confined chiefly to the southern counties of the "Western Shore" of the Chesapeake Bay but is now being extended to the "Eastern Shore."

This paper deals primarily with the subsurface geology of two of the "Western Shore" counties. The rocks are unconsolidated sediments of Cretaceous and Tertiary age, and the formations dip roughly southeast at 10 to 20 feet to the mile. Subsurface geologic maps show the contact surfaces between the formations.

The materials studied, on which the maps are based, are samples from recently drilled water wells. The method of collecting, studying, and filing samples is described briefly. (Drillers are compelled by law to furnish samples to the Department if requested.)

The most interesting general result so far is the finding of upper Eocene Jackson and Paleocene beds in the subsurface of the "Western Shore." These beds are not known definitely to outcrop in the State.

PRE-PENNSYLVANIAN ROCKS OF NORTHERN RHODE ISLAND*

Alonzo W. Quinn

Brown University, Providence, R. I.

The Narragansett basin and the Woonsocket basin of Rhode Island are underlain by downfolded or downfaulted sandstone, shale, and conglomerate of Pennsylvanian age. These beds are involved in Appalachian folds trending north-south.

Underlying the Pennsylvanian beds with marked discordance are metamorphic and igneous rocks of considerable variety. The oldest of these, the Precambrian (?) Blackstone Series, consist of schists,

*Published by permission of the Director, U. S. Geological Survey.

greenstone, quartzite, and marble; they are exposed prominently along the Blackstone Valley and in smaller areas as far south as East Greenwich. These metamorphic rocks have been intruded by two groups of igneous rocks. The older igneous rocks include the Esmond granite, the Grant Mills granodiorite, and several bodies of quartz diorite. Evidence that these rocks were intruded as liquid magmas is widespread, although locally they exhibit features of granitization. These igneous rocks are Devonian or older. The younger group of igneous rocks includes the Quincy granite and a related granite porphyry in the northern part of the State, and several types of granitic rocks with their extrusive equivalents in the East Greenwich area. This group is younger than the Esmond granite and older than the Pennsylvanian conglomerate of the Narragansett basin; Mississippian age seems probable. The younger intrusive rocks appear to have been intruded as liquid magmas.

Recent detailed mapping has shown that some of the granite gneiss formerly included in the Sterling granite gneiss of late Carboniferous or post-Carboniferous age is older than the Esmond granite and younger than the Blackstone Series.

SOURCE AND CORRELATION OF THE DEEPKILL CONGLOMERATES

Mary Harvey Ross

Cornell University, Ithaca, N. Y.

Small conglomerate lenses characterize exposures of the Lower Ordovician Deepkill shale in the Hudson Valley. These conglomerates are composed of limestone, with some chert, shale, dolomite, and sandstone pebbles in a calcareous, carbonaceous matrix.

Petrographic study was made of these conglomerates to (1) establish criteria for recognition of unidentified local Deepkill conglomerates; (2) investigate the normal marine series of Cambro-Ordovician rocks in the Champlain Valley as possible sources of pebbles.

The first phase of the investigation showed that not only could the Deepkill conglomerates be distinguished from the other local conglomerate, the Schodack, but they could be identified as to older and younger Deepkill and correlated with each other. Evidence was found that the Schodack conglomerate is a breccia of the local Schodack limestone.

The second phase of the study is based on the assumption that the Deepkill shale was deposited in the uplifted center of a geosyncline with limestones and dolomites exposed on its borders furnishing the pebbles for the conglomerates. Results obtained are not final, but they strongly indicate that only upper Cambrian materials are present in the lowest Deepkill, middle Canadian in the middle Deepkill, and Fort Cassin and Chazyan in the upper Deepkill.

STUDY OF THE PENNSYLVANIA ANTHRACITE FIELDS*

Howard E. Rothrock

U. S. Geological Survey, Mount Carmel, Penna.

A study of the Pennsylvania Anthracite fields, begun in October 1947 by the U. S. Geological Survey, was undertaken chiefly as an aid in prolonging mining operations. This assistance will be effected by issuing publications that (1) show accurately the positions and areal extent of the outcrops of all known coal beds as an aid to stripping operations; (2) correlate the nomenclature and structural relationships of the coal beds to assist the operators in planning and integrating development of adjoining properties; (3) supply geological information pertinent to dewatering and flooding problems; and (4) possibly direct attention to neglected or undiscovered reserves of coal. Collateral objectives include studies of the stratigraphy of the coal-bearing rocks, the lithology of the coal, and the tectonics of Appalachian deformation in the Anthracite fields. The reports will also bring up to date the Grand Atlas of the Anthracite fields published by the Second Pennsylvania Geological Survey in 1881 to 1891.

To make this information available as promptly as possible, publications will be issued in units

*Published by permission of the Director, U. S. Geological Survey.

that cover one-sixth of a 7½ minute topographic quadrangle, or about 8½ square miles. The units will consist of several sheets, approximately 40 by 60 inches in size, containing maps at a scale of 1:6000, cross sections, and supporting text. These publications will represent extensive collaboration between the Geological Survey and the coal operators whose records are indispensable to the success of the project.

Parts of the material prepared for the reports have already proved to be of economic value in appraising a dewatering project to reactivate a mine, and in planning a flooding project to extinguish a mine fire. Conclusions regarding the geologic characteristics of the fields are chiefly in the formative stage, but certain hypotheses are gaining credence, such as: variation of facies and stratigraphic intervals in short distances; lack of continuity in many of the minable coal beds; consistent relationship between the thickness of incompetent strata and the degree of their deformation; thickening of coal along fold axes and thinning on the limbs; incompetence and shearing of the limbs of folds as their axial planes become overturned with consequent development of longitudinal thrust faults; tendency of bedding-plane faults to occur in steeply dipping strata and in the ends of synclines; and development of zones of shearing and faulting in coal beds at angles of approximately 45° to the longitudinal axes of the folds.

RAMPARTS ON THE ELEVATED ATOLL OF KITA DAITO JIMA*

Raymond A. Saplis and Delos E. Flint

U. S. Geological Survey, Washington, D. C.

Kita Daito Jima appears to be an excellent example of a well-preserved elevated atoll. A central depression, about 1 mile in diameter, is surrounded by a rim that ranges in width from half a mile on the southwest to 1¼ miles on the northeast. The rim is highest adjacent to the central depression, and seaward becomes lower in a series of terrace levels. A well-developed natural limestone wall occurs along the inner edge of the rim, and remnants of walls occur on the outer edges of the terraces. Similar walls on the limestone terraces of other islands in the Pacific have been ascribed to solution, and some writers believe that they may be a factor in determining the differential uplift of an island. The walls of Kita Daito Jima are believed to have been formed by the secondary cementation of poorly consolidated reef limestones on sea cliffs and the subsequent more rapid solution of the poorly consolidated limestone adjacent to the well-cemented walls. Tilting does not appear to have been a factor in the formation of the walls on Kita Daito Jima.

PLEISTOCENE GEOLOGY OF THE UPPER TETON RIVER, CENTRAL MONTANA

J. P. Schafer

Brown University, Providence, R. I.

The Teton River rises in the Rocky Mountains and flows eastward across the Great Plains to join the Missouri River system. The topography of the plains immediately previous to Wisconsin time was dominated by the dissected remnants of two sets of terraces. Piedmont glacier tongues of Wisconsin age extended 1–10 miles onto the plains from the principal mountain canyons. Two later glacial substages are represented by moraines and pro-talus ramparts in some of the cirques. The younger of these features are probably of the same age as the "1850" moraines directly in front of the glaciers in Glacier National Park.

The continental ice sheet advanced westward in the lower part of the Teton Valley to a point about 30 miles east of the mountain front, probably shortly after the retreat of the piedmont glaciers had begun. The ice sheet dammed the valley, producing an extensive but short-lived lake in which numerous erratics of Canadian origin were carried westward by icerafting. Subsequent to the withdrawal of the ice front some distance to the east, a thick valley fill accumulated.

Additional evidences of climatic changes are provided by features due to former wind and frost

*Published by permission of the Director, U. S. Geological Survey.

action, by characteristics of slopes, by the existence of several low stream terraces, and by the distribution of calcium carbonate concentrations in soils.

FREQUENCY-DISTRIBUTION ANALYSIS OF SLOPES

Arthur N. Strahler

Columbia University, New York, N. Y.

In the quantitative analysis of erosional landforms one of several topographic form elements requiring measurement is slope angle of valley walls. Sampling of slope angles in several regions, differing widely in lithology, relief, climate, vegetation, and soils, has yielded data suited to treatment by standard methods of frequency-distribution statistics. Histograms have been drawn on rectangular and polar co-ordinates. Determinations of means, dispersions, skewness, and normal distribution have provided a quantitative basis for slope description and significance tests.

Quantitative comparisons and field study show that slopes produced in relatively homogeneous materials in the fluvial erosion cycle are of three principal types: (1) Slopes of cohesive, fine-textured materials, such as clays or clay-rich soil mantle, or of strong, massive bedrock commonly have means of 40° to 50°. Examples were found in the California Coast Ranges and in various badlands. Soil mantle on these slopes is subject to rapid sliding and flowage movements. (2) Slide-rock slopes, such as those in the Catskills and in some desert ranges, are governed by the angle of repose of rock fragments, in the range 30° to 35°. (3) Slopes reduced below the angle of repose by dominant sheet erosion and creep have means ranging from 20° to as low as 1.5°. Whereas the first two types are associated with steep-gradient stream systems in process of rapid channel corrasion and basal slope cutting, the third group seems to develop later in a stage of diminishing relief and slow channel corrasion.

SPECTROCHEMICAL ANALYSIS OF ROCKS*

Lester W. Strock and Ladislav Dejnozka

Saratoga Laboratories, Saratoga Springs, N. Y.

Spectrochemical methods are widely used for determining minor and trace constituents in geological materials. Saratoga Laboratories, Inc., has been attempting for several years to extend the range of usefulness of spectrochemical methods in geological research and control by devising procedures for determining major constituents. Some preliminary results, involving a $SrCO_3$ mechanical mixture base and a $K_2B_2O_4$:B_2O_3 fusion melt, were reported last year (G.S.A. Bull., vol. 59, p. 1355).

The present paper presents new data, a high dilution of sample with carbon powder and a metallic matrix of germanium metal. A statistical evaluation of the results achieved shows the necessity of some additional research, but that spectrochemical determination of major constituents of rocks is definitely possible.

SYNTHESIS OF PIEZOELECTRIC MINERALS FOR FREQUENCY CONTROL

Hugh H. Waesche

Signal Corps Engineering Laboratories, Fort Monmouth, N. J.

A program for piezoelectric crystal synthesis was initiated by the Signal Corps at the close of World War II because world reserves of natural, radio-grade quartz crystals had been depleted by war-time demand while no new sources had been discovered. Previously, during 1944 and 1945 it had been suggested that the possibility of synthesizing quartz crystals be explored to offset the lack of this strategic material. Interest in the problem was spurred further by the discovery after V. E.

*This work now supported by ONR Grant #88900.

Day, that the Germans had developed what was believed to be a successful hydrothermal method for synthesizing quartz crystals. By the end of 1946 the Signal Corps had two quartz synthesis contracts in effect. In addition, Naval Research Laboratories and one private organization were making independent investigations in this field; all except the former were attempting to use the German, hydrothermal method, which depended on the difference in solubility of vitreous and crystalline silica. Although early efforts to synthesize quartz by the American groups with this system were disappointing, continued research resulted in considerable success with another hydrothermal method utilizing crystalline quartz as source and seed material. A Government-sponsored and an independent agency both contributed to the more successful method. Another Signal Corps-sponsored contractor had greatly improved the German process.

In addition to quartz, the Signal Corps has sponsored successful synthesis of crystalline nepheline, aluminum phosphate (berlinite), and tourmaline. The investigations are continuing with quartz synthesis showing the greatest possibility of ultimate success in attaining all the desired goals with the least difficulty.

PRELIMINARY REPORT ON GEOLOGY OF POPOCATEPETL, MEXICO

Sidney E. White

Syracuse University, Syracuse, N. Y.

The volcano Popocatepetl, Mexico, has a complex history of vulcanism, deep erosion, and glaciation. Barranca de Nexpayantla, a valley deeply eroded into the northwest side of the volcanic mass, consists of a fan-shaped amphitheater, cut into interbedded lava flows and pyroclastics, the head of which is separated from the cone of Popocatepetl by a low saddle. This barranca downstream, V-shaped in general aspect, contains a gorge incised into massive volcanic breccia. A few terrace remnants of flood gravels in re-entrant pockets and wider portions of the gorge, as well as recent flood deposits, are not yet correlated with stream terraces downstream.

Smaller, narrow barrancas cut into the north side of the cone of Popocatepetl may result from local greater extension of the permanent ice cap near the close of the Pleistocene epoch. Possible glaciation is indicated by lateral ridges (possible lateral moraines), a polish on roche moutonnee-shaped lava bedrock, striations on roches moutonnees, scratches on basaltic boulders, numerous abandoned stream channels, and evidence of stream erosion. Several of these features, as well as the absence of glacially soled boulders, suggest the alternate possibility of mud-flow action. Evidence of possible multiple glaciation is not yet found.

No barrancas exist on the east side of the mountain. From a study of aerial photographs, similar barrancas appear on the west side of the cone. The south side of the volcano was not seen. Plans contemplate continuation of the field work. Kodachrome slides illustrate the features discussed.

CAMBRIAN STRATIGRAPHIC NOMENCLATURE IN EASTERN PENNSYLVANIA

Bradford Willard

Lehigh University, Bethlehem, Penna.

There is confusion in Cambrian stratigraphic terminology in eastern Pennsylvania. At present the sequences in use are:

Lehigh Valley	*Buckingham Valley*
Conococheague ("Allentown") limestone	Conococheague limestone
Tomstown limestone	Elbrook limestone
Hardyston quartzite	Chickies quartzite
	Hellam conglomerate member at base

Correlations of the limestones with type localities are doubtful or unproven. Correlation of the quartzites appears to be established. The proposed terminology is:

Allentown limestone
Leithsville limestone
Hardyston quartzite (Lehigh Valley)
Chickies quartzite (Buckingham Valley)

These names for the limestones are local but are already defined in the literature. Their use avoids implied correlations which have not been unequivocally established.

QUANTITATIVE COMPARATIVE STUDY OF FRACTURES IN GNEISSES AND OVERLYING SEDIMENTS OF NORTHERN NEW JERSEY

Howard J. Pincus

Ohio State University, Columbus, Ohio

Fractures in Precambrian crystalline rocks are compared with those of the overlying Paleozoic sedimentary rocks in three areas in the New Jersey Highlands.

A summary history of the quantitative analysis of rock fractures is presented.

Problems involved in collecting and treating statistically the quantitative data are discussed in detail. A method is proposed for plotting orientation data on rectangular co-ordinates; the resulting contour patterns are interpreted, and a comparison is made with the Schmidt net. The number of observations required at each locality is determined by the addition of successive increments of data until the contour pattern is stabilized.

The decision as to whether the data are clustered, or scattered at random, is made by use of the Poisson Exponential Binomial Limit. A method is set forth for outlining the borders of point-clusters on the diagrams; these border values are used in evaluating cluster co-ordinates and supplying form contours.

The summary data (mean fracture planes) yielded by the statistical treatment are used in the following investigations: the relation of mean fracture planes to regional structural grain; the number of mean fracture planes at Paleozoic localities as compared with the number at Precambrian localities; the heights of contoured peaks on the diagrams of the Paleozoic data as compared with those for the Precambrian data; the dihedral angles between mean fracture planes and bedding planes or foliation at the respective localities; the dihedral angles between mean fracture planes at each locality; the comparison of form contours among structurally similar but lithologically and/or chronologically different localities; the use of large fractures in reconnaissance; the trend of the mean fracture planes as compared with that of linear features visible on air photographs of one of the areas.

The effects of the Paleozoic deformation are "erased" by an arbitrary geometric method; the deformation of the gneisses seems to have taken place through mechanisms fundamentally different from those involved in deforming the overlying sediments. The validity and limitations of the method of restoration are discussed.

The angles of dip of fractures in the gneisses and in the sedimentary rocks are compared; the significance of steeply dipping fractures is discussed.

An inferred sequence of geologic events is outlined, with emphasis on the evolution of the present fracture patterns.

Publications of The Geological Society of America—Continued

48. North American Pleospongia. V. J. Okulitch. 1943. 112 p., 18 pls., 19 figs. $1.50.
49. Ozarkian and Canadian Cephalopods. Part II. Brevicones. E. O. Ulrich, A. F. Foerste, and A. K. Miller, 1943. 240 p., 70 pls., 15 figs. $3.00.
50. Bibliography of Economic Geology of South America. J. T. Singewald, Jr. 1943. 159 p. $1.00.
51. Miocene Radiolarian Faunas from Southern California. A. S. Campbell and B. L. Clark. 1944. 76 p., 7 pls. $0.85.
52. Geology and Paleontology of the Permian Area, Northwest of Las Delicias, Southwestern Coahuila, Mexico. R. E. King, C. O. Dunbar, P. E. Cloud, Jr., and A. K. Miller. 1944. 172 p., 45 pls., 29 figs. $2.40.
53. Study and Revision of *Archimedes* (Hall). G. E. Condra and M. K. Elias. 1944. 243 p., 41 pls., 6 figs. $3.00.
54. Origin of Mammals Based upon Cranial Morphology of Therapsid Subordders. E. C. Olson. 1944. 136 p., 27 figs. $1.20.
55. Check List of California Tertiary Marine Mollusca. A. M. Keen and H. Bentson. 1944. 280 p., 4 figs. $2.25.
57. Radiolaria from Upper Cretaceous of Middle California. A. S. Campbell and B. L. Clark. 1944. 61 p., 8 pls., 2 figs. $0.70.
58. Ozarkian and Canadian Cephalopods. Part III: Longicones. E. O. Ulrich, A. F. Foerste, A. K. Miller, A. G. Unklesbay. 1944. 226 p., 68 pls., 9 figs. $3.00.
59. Upper Devonian Corals of the Mackenzie River Region, Canada. Stanley Smith. 1945. 126 p., 35 pls. $2.00.
60. Glacial Map of North America: Part I. Glacial map (in color); Part 2. Explanatory notes. By Committee on Glacial Map, R. F. Flint, *Chairman*. 1945. $2.00.
61. Geological Map of South America: Part 1. Preliminary geological map (in black and white); Part 2. Foreword and explanation of legend. By South American Map Committee, A. I. Levorsen, *Chairman*; G. W. Stose, *Editor*. 1945. $2.00.

MEMOIRS

1. Stratigraphy of Western Newfoundland. Charles Schuchert and C. O. Dunbar. 1934. 123 p., 11 pls., 8 figs. $2.40.
2. Paleozoic Plankton of North America. Rudolf Ruedemann. 1934. 141 p., 26 pls., 6 figs. $2.40.
3. Evolution of the Congo Basin. A. C. Veatch. 1935. 183 p., 10 pls., 8 figs. $2.10.
4. Geology in the Coastal Atlas of Western Algeria. R. van V. Anderson. 1936. 450 p., 19 pls., 2 figs. $4.20.
5. The Universal Stage. R. C. Emmons. 1943. 205 p., 13 pls., 95 figs. $2.40.
9. American Tertiary Foraminifera and Corals. T. Wayland Vaughan and John W. Wells. 1945. 200 p., 49 pls., 11 figs. $3.20.
10. Radiolaria from the Kreyenhagen Formation near Los Banos, California. B. L. Clark and A. S. Campbell. 1945. 65 p., 7 pls. $1.20.
11. Mollusca of the Tertiary Formations of Northeastern Mexico. Julia Gardner. 1945. 332 p., 28 pls., 1 fig. $3.90.
12. Revision of the Upper Cambrian Faunas of New Jersey. B. F. Howell. 1945. 46 p., 8 pls. $1.00.
13. Pennsylvanian Geology of a Part of the Southern Appalachian Coal Field. H. R. Wanless. 1946. 162 p., 40 pls., 1 fig. $3.90.
14. Brachiopoda of the Independence Shale. M. A. Stainbrook. 1945. 74 p., 6 pls., 2 figs. $1.20.
15. Tungsten Mineralization in the United States. P. F. Kerr. 1946. 241 p., 23 pls., 34 figs. $3.00.
16. Eocene Faunas from the Department of Bolivar, Colombia. B. L. Clark and J. W. Durham. 1946. 126 p., 23 pls., 1 fig. $2.10.
17. Permian Fusulinids of California. M. L. Thompson, H. E. Wheeler, and J. C. Hazzard. 1946. 77 p., 18 pls., 4 figs. $1.50.
18. Lineation. A Critical Review and Annotated Bibliography. Ernst Cloos. 1946. 122 p., 10 pls., 15 figs. $1.80.
19. Graptolites of North America. Rudolf Ruedemann. 1947. 652 p., 92 pls., 1 fig. $9.00.
20. Corals from the Gulf of California and the North Pacific Coast of America. J. Wyatt Durham. 1947. 68 p. 14 pls., 2 figs. $1.70.
21. Origin and Development of Craters. T. A. Jaggar. 1947. 508 p., 87 pls., 14 figs. $6.00.
22. Reconnaissance Geology of Portions of Victoria Island and Adjacent Regions, Arctic Canada. A. L. Washburn. 1947. 142 p., 32 pls., 4 figs. $4.00.
23. Tertiary Nautiloids of the Americas. A. K. Miller. 1947. 234 p., 100 pls., 30 figs. $4.50.
25. Evolution of the Horse Brain. Tilly Edinger. 1948. 177 p., 4 pls., 24 figs. $2.00.
26. Bibliographic Index of Permian Invertebrates. C. C. Branson. 1948. 1049 p. $9.50.
27. Propagation of Sound in the Ocean. J. L. Worzel, Maurice Ewing, C. L. Pekeris. 1948. 205 p., 23 pls., 89 figs. $2.75.
29. Batholith and Associated Rocks of Corona, Elsinore, and San Luis Rey Quadrangles, California. E. S. Larsen, Jr. 1948. 182 p., 8 pls., 16 figs. $4.50.
30. Mineralogical and Structural Evolution of Metamorphic Rocks. F. J. Turner. 1948. 342 p., 85 figs. $3.00.
31. Reconnaissance of the Geology and Oil Possibilities at Baja California, Mexico. C. H. Beal. 1948. 138 p., 11 pls. $3.00.
32. Stratigraphy and Fauna of the Agua Salada Group, State of Falcón, Venezuela. H. H. Renz. 1948. 219 p., 12 pls., 15 figs. $2.75.
33. Geology and Origin of South Park, Colorado. J. T. Stark *et al.* 1949. 188 p., 18 pls., 22 figs. $3.75.
34. Permian Crinoid Calcelispongia. Curt Teichert. 1949 132 p., 26 pls., 24 figs. $2.50.
35. Geology of the Coast Ranges Immediately North of the San Francisco Bay Region, California. C. E. Weaver. 1949. 242 p., 14 pls., 2 figs. $6.50.
36. Geology of the Lake Titacaca Region, Peru and Bolivia. N. D. Newell. 1949. 111 p., 21 pls., 14 figs. $5.00.
37. Bibliography of Fossil Vertebrates, 1939–1943. By C. L. Camp, S. P. Welles, and Morton Green. 1949. 371 p. $4.50.
38. Lower Cretaceous Stratigraphy in Southeastern Arizona. Alexander Stoyanow. 1949. 169 p., 27 pls., 2 figs. $2.50.
39. Sedimentary Facies in Geologic History. C. R. Longwell, *Chairman*. 1949. 171 p. $1.75.
40. Revision of the Families and Genera of the Devonian Tetracorals. E. C. Stumm. 1949. 92 p., $2.00.
41. American Permian Nautiloids. A. K. Miller and Walter Youngquist. 1949. 218 p., 59 pls., 39 figs. $3.60.

Publications of The Geological Society of America

Publications may be purchased at indicated prices on order accompanied by remittance addressed to The Geological Society of America, 419 West 117 Street, New York 27, N. Y.

BULLETIN

Monthly. Advance subscription, $15 per year; separate numbers $1.50; back yearly volumes, prior to 1935, $12.00 per volume; 1935–, $15.00 per volume. Ten-year indexes covering vols. 11–20; 31–40; 41–50. $1.50 per copy.

PROCEEDINGS

Annually. Contains business of Annual Meeting, reports of committees, and memorials. $1.50 per volume.

HISTORY

THE GEOLOGICAL SOCIETY OF AMERICA, 1888–1930: A Chapter in Earth Science History. By H. L. Fairchild. 1932. 223 p., 18 pls. $2.50.

BIBLIOGRAPHY OF GEOLOGY EXCLUSIVE OF NORTH AMERICA

Annually, 1933–1940; biennially, 1941–1946; annually, 1947–. By J. M. Nickles, Marie Siegrist, and Eleanor Tatge. Vols. 1 inclusive, $2.50 per volume; Volume 9, $2.75; Volume 10, out of stock; Volume 11, $3.25; Volume 12, $3.50; Volume 13, $3.25.

SPECIAL PAPERS

1. BIBLIOGRAPHY AND INDEX OF PALEOZOIC OSTRACODA. R. S. Bassler and Betty Kellett. 1934. 500 p., 24 figs. $3.00.
2. FOSSIL CRUSTACEA OF THE ATLANTIC AND GULF COASTAL PLAIN. M. J. Rathbun. 1935. 160 p., 26 pls., 2 figs. $1.50.
3. FOSSIL NON-MARINE MOLLUSCA OF NORTH AMERICA. Junius Henderson. 1935. 313 p. $2.10.
4. NUCULID BIVALVES OF THE GENUS ACILA. H. C. Schenck. 1936. 149 p., 18 pls., 15 figs. $1.50.
5. GEOLOGY OF SAINT JOHN, NEW BRUNSWICK. A. O. Hayes and B. F. Howell. 1937. 146 p., 9 pls., 4 figs. $1.50.
6. HISTORY OF THE GRAND CANYON OF THE YELLOWSTONE. A. D. Howard. 1937. 159 p., 21 pls., 31 figs. $1.80.
7. ATLANTIC SUBMARINE VALLEYS OF THE UNITED STATES AND THE CONGO SUBMARINE VALLEY. A. C. Veatch and Pan A. Smith. 1939. 101 p., 5 charts, 10 pls., 28 figs. $4.80.
8. MIDDLE DEVONIAN CORALS OF OHIO. G. A. Stewart. 1938. 120 p., 20 pls., 2 figs. $1.50.
9. FOSSIL SNAKES OF NORTH AMERICA. C. W. Gilmore. 1938. 96 p., 4 pls., 38 figs. $0.90.
10. STRATIGRAPHY AND MOLLUSCA OF THE EOCENE OF WESTERN OREGON. F. E. Turner. 1938. 130 p., 23 pls., 7 figs. $1.80.
11. GEOLOGY AND PALEONTOLOGY OF THE MINGAN ISLANDS, QUEBEC. W. H. Twenhofel. 1938. 132 p., 24 pls., 1 fig. $1.80.
12. TERTIARY FLORA FROM THE RIO PICHILEUFU, ARGENTINA. E. W. Berry. 1938. 149 p., 56 pls., 11 figs. $2.10.
13. OZARKIAN AND CANADIAN BRACHIOPODA. E. O. Ulrich and G. A. Cooper. 1938. 323 p., 58 pls., 14 figs. $3.90.
14. DEVONIAN AMMONOIDS OF AMERICA. A. K. Miller. 1938. 262 p., 39 pls., 41 figs. $2.70.
19. CAMBRIAN MEROSTOMATA. G. O. Raasch. 1939. 146 p., 21 pls., 14 figs. $1.50.
21. PALEONTOLOGY AND STRATIGRAPHY OF THE SILURIAN ROCKS OF THE PORT DANIEL-BLACK CAPE REGION, GASPE. S. A. Northrop. 1939. 302 p., 28 pls., 1 fig. $3.00.
22. LOWER MISSISSIPPIAN ROCKS OF THE EAST-CENTRAL INTERIOR. P. B. Stockdale. 1939. 248 p., 26 pls., 2 figs. $2.40.
23. BIBLIOGRAPHIC INDEX OF NORTH AMERICAN DEVONIAN CEPHALOPODA. E. M. Kindle and A. K. Miller. 1939. 179 p. $1.20.
26. PERMIAN AMMONOIDS OF THE GUADALUPE MOUNTAIN REGION AND ADJACENT AREAS. A. K. Miller and W. M. Furnish. 1940. 242 p., 44 pls., 59 figs. $2.70.
27. BIBLIOGRAPHY OF FOSSIL VERTEBRATES 1928–1933. C. L. Camp and V. L. VanderHoof. 1940. 503 p. $4.20.
28. REVIEW OF THE PELYCOSAURIA. A. S. Romer and L. I. Price. 1940. 538 p., 46 pls., 71 figs. $4.20.
29. PHACOPID TRILOBITES OF NORTH AMERICA. D. M. Delo. 1940. 135 p., 13 pls. $1.20.
31. SUBMARINE TOPOGRAPHY OFF THE CALIFORNIA COAST: CANYONS AND TECTONIC INTERPRETATION. F. P. Shepard and K. O. Emery. 1941. 171 p., 18 pls., 42 figs., 4 charts. $3.90.
35. GEOLOGY OF THE "MARTIC OVERTHRUST" AND THE GLENARM SERIES IN PENNSYLVANIA AND MARYLAND. Ernst Cloos and Anna Hietanen. 1941. 207 p., 28 pls., 58 figs. $4.20.
36. HANDBOOK OF PHYSICAL CONSTANTS. Edited by Francis Birch, *Chairman, et al.* 1942. 325 p., 19 figs. $1.70.
37. OZARKIAN AND CANADIAN CEPHALOPODS, PART I, NAUTILICONES. E. O. Ulrich, Aug. F. Foerste, A. K. Miller, and W. M. Furnish. 1942. 157 p., 57 pls., 23 figs. $2.40.
38. TEREBRATULOID BRACHIOPODA OF THE SILURIAN AND DEVONIAN. P. E. Cloud, Jr. 1942. 182 p., 26 pls., 17 figs. $1.80.
39. EOCENE RADIOLARIAN FAUNAS FROM THE MT. DIABLO AREA, CALIFORNIA. B. L. Clark and A. S. Campbell. 1942. 112 p., 9 pls., 5 figs. $1.00.
40. HADROSAURIAN DINOSAURS OF NORTH AMERICA. R. S. Lull and N. E. Wright. 1942. 242 p., 31 pls., 90 figs. $2.70.
42. BIBLIOGRAPHY OF FOSSIL VERTEBRATES, 1934–1938. C. L. Camp, D. N. Taylor, and S. P. Welles. 1942. 663 p. $5.70.
43. MIOCENE FISHES OF SOUTHERN CALIFORNIA. L. R. David. 1943. 193 p., 16 pls., 39 figs. $2.00.
44. REVISION OF THE SUBORDERS, FAMILIES, AND GENERA OF THE SCLERACTINIA. T. W. Vaughan and J. W. Wells. 1943. 363 p., 51 pls., 39 figs. $3.90.
45. BIBLIOGRAPHIC AND FAUNAL INDEX OF PALEOZOIC PALMATOZOAN ECHINODERMS. R. S. Bassler and M. W. Moodey. 1943. 734 p. $5.70.
46. EVOLUTION AND CLASSIFICATION OF PALEOZOIC CRINOIDS. R. C. Moore and L. R. Laudon. 1943. 153 p., 14 pls., 18 figs. $1.20.
47. MESOZOIC AND CENOZOIC ARCIDAE FROM THE PACIFIC SLOPE OF NORTH AMERICA. P. W. Reinhart. 1943. 117 p., 15 pls., 3 figs. $1.50.

(Continued on inside back cover)

UNIV

INDEX TO VOLUME 60 (JULY–DECEMBER)*

ccuracy of the lead method for the absolute measurement of geologic ages. By J. P. Marble 1907
s, C. E. (With G. Tunell): Crystal structure of borolite from Illogan, Cornwall 1925
DDINGTON, A. R.: Miniature cauldrons 1935
ET, R. V.: Cambrian stratigraphy of the southern Front Range, Colorado 1959
olian Buttes till (New name). By W. C. Putnam 1281
ge determinations of pegmatites in Topsham, Maine. By V. E. Shainin 1727
ge of the last Pluvial in New Mexico and Texas. By Ernst Antevs 1871
ER, T. P. (With W. H. Irwin *et al.*): Development and use of multiple packers by the Bureau of Reclamation for ground-water observation in engineering geology 1898
ity phase of shallow-focus submarine earthquakes. By Frank Press, Maurice Ewing, and Ivan Tolstoy 1956
BANESE, John: Peridotite body in the Laramie Mountains, Wyoming 1959
BRITTON, C. C., Jr., and Smith, J. Fred, Jr.: Marfa Basin, Hudspeth County, Texas 1869
, Richards, Arthur, Brokaw, A. L., Reinemund, J. A., Phoenix, D. A.: Structural features associated with lead and zinc ores of the Goodsprings district, Nevada 1869
– (With J. F. Smith, Jr.): Conglomerates of western Trans-Pecos Texas and their relation to a tectonic boundary 1921
ALLEN, V. T.: Leucoxene problem 1870
ALLISON, I. S.: Fault pattern of south-central Oregon 1935
Alpha activity of rocks and sediments by scintillation counting. By H. D. Holland and J. L. Kulp 1896
Alpine glaciation. By L. L. Ray 1475
Alteration features at Silver Bell, Arizona. By P. F. Kerr. 1901
Alternating layer sequence of rectorite. By W. F. Bradley 1875
Analyses
  Chemical
    Hawaiian Islands. By G. A. Macdonald 1541
    Igneous rocks of Buck Hill quadrangle, Texas. By S. S. Goldich and M. A. Elms 1133
ANDERSON C. A.: Older Precambrian structure in Arizona 1870
ANTEVS, Ernst: Age of the last pluvial in New Mexico and Texas 1871
Approximations in geophysics. By Beno Gutenberg 1954
ARELLANO, A. R. V., and Azcon, Ernesto: Pre-Equus horses from Goleta (Morelia) Michoacan, Mexico 1871
Assimilation
  Hawaiian islands. By G. A. Macdonald 1541
  – (?) of micaceous schist by diabase. By W. H. Tomlinson 1924
Atlantic Ocean
  Hydrography and the Mid-Atlantic Ridge. By Ivan Tolstoy and Maurice Ewing 1527
AXELROD, D. I.: Eocene and Oligocene formations in the western Great Basin 1935
Azcon, Ernesto (With A. R. V. Arellano): Pre-Equus horses from Goleta (Morelia) Michoacan, Mexico 1871

BADER, Henri: Trends in Glaciology in Europe 1309
BAILLY, R. J., and Holke, K. A.: Microscope and refractometer for infra-red light 1871
BANDY, O. L.: Ontogenetic variation in Eponides Mexicanus (Cushman) 1949
BARGHOORN, E. S.: Geological and botanical study of the Brandon lignite and its significance in coal petrology. 1872
BARKSDALE, J. D.: Volcanic rocks in the Candelaria district, west-central Nevada 1936
BARLOW, A. C. (With W. H. Irwin *et al.*): Development and use of multiple packers by the Bureau of Reclamation for ground-water observation in engineering geology 1898
BARTLEY, J. H.: Simpson group, west Texas and southeastern New Mexico 1872
Basement complex of the Panhandle of Texas. By Robert Roth 1671
Basin Range faulting near Salt Lake City, Utah. By R. E. Marsell 1941
BEARD, C. N.: Stratigraphy and structure of the Capitola quadrangle, California 1936
BEHRE, C. H., Jr., and Fries, Carl, Jr.: Geomorphic events of east-central Mexico 1873
BENIOFF, Hugo: Directional characteristics of strain seismograph parts 1953
—: Earthquakes and rock creep 1936
—: Seismic evidence for the fault origin of oceanic deeps. 1837
BENSON, W. E.: Golden Valley formation of North Dakota 1873
BERRY, E. W.: Fossil plants from Santee Valley, South Carolina 1874
Beryl at Mt. Mica, Maine. By C. S. Hurlbut, Jr. 1897
Biogeography and the nature of continents. By Albert Wolfson 1931
Biogeography of the Pleistocene. By E. S. Deevey, Jr. 1315
BLUME, J. A.: Plans for the earthquake engineering research institute 1953
BOARDMAN, Leona: Geologic mapping in the United States 1125
Boos, M. F.: Structure of the Precambrian, Denver Mts. Parks quadrangle, Colorado 1874
BOWEN, N. L., and Tuttle, O. F.: System $NaAlSi_2O_6$–$KAlSi_2O_6$–H_2O 1874
— (With O. F. Tuttle): High-temperature albite 1925
BRADLEY, W. F.: Alternating layer sequence of rectorite. 1875
— (With R. E. Grim and R. S. Dietz): Clay-mineral composition of some sediments from the Pacific Ocean off the California Coast and the Gulf of California ... 1785
BROKAW, A. L. (With C. C. Albritton *et al.*): Structural features associated with lead and zinc ores of the Goodsprings district, Nevada 1869
BRUCE, E. L., and Ross, J. S.: Relation of the Seine series to granite at East Shoal Lake, Ontario 1875
BRYSON, R. P.: Distribution, occurrence and resources of sub-bituminous coal and lignite in the western United States 1875
BUCHER, W. H.: Recent results of suboceanic geology and major earth problems 1876
Buck Hill quadrangle, Texas, Stratigraphy and petrology of. By S. S. Goldich and M. A. Elms 1133
BUERGER, M. J.: General aspects of disorder in minerals. 1876
— (With Edward Washken): Effect of potassium on the nepheline-carnegieite transformation 1927
BUFFINGTON, E. C. (With R. S. Dietz): Sea-floor investigations in the North Pacific and Bering Sea 1882
BURMA, B. H. (With L. M. Cline): Paleoecological study of the Pennsylvanian Exline limestone of Iowa and Missouri 1880

* Full titles of papers are in **boldface** type; page numbers of abstracts are in *italics*.

BUTLER, B. S.: Setting of Arizona in Cordilleran structure ... *1877*

BUTLER, C. R.: Geology of the northern part of the Sangre de Cristo Mountains, Colorado ... *1959*

BYERLY, PERRY AND EVERNDEN, J.: First motion from deep and shallow shocks ... *1953*

— — ROMNEY, CARL: Nevada earthquakes ... *1953*

CADY, W. M. (With R. E. WALLACE, *et al.*): Thermal metamorphism in the central Kuskokwim region, southwestern Alaska ... *1946*

California Coast and the Gulf of California, Clay-mineral composition of some sediments from the Pacific Ocean off the. By R. E. Grim, *et al.* ... 1785

Cambrian stratigraphic nomenclature in eastern Pennsylvania. By Bradford Willard ... *1976*

— stratigraphy of the southern Front Range, Colorado. By R. V. Addy ... *1959*

CAMP, C. L.: Mesozoic boundaries and faunal changes ... *1877*

CAMPBELL, C. D.: Favorable ore zones of the Northport district, northeastern Washington ... *1878*

— (With C. E. B. CONYBEARE): Petrology of the red radioactive zones north of Goldfields, Saskatchewan. *1881*

Canyons revealed by diving, Terrestrial topography of submarine. By F. P. SHEPARD ... 1597

CARLSTON, C. W.: Drainage Patterns ... *1967*

CARR, D. R. (With J. L. KULP): Surface area of deep-sea sediments ... *1902*

CARSOLA, A., DIETZ, R. S., AND RUSSELL, R. D.: Submarine geology of two northeast Pacific sea mounts ... *1878*

CARY, A. S.: Natural clay grout in openwork gravel ... *1878*

Cause of an ice age. By F. K. Morris ... *1910*

CHADWICK, G. H.: Glacial molding of the Gulf of Maine ... *1967*

CHAISSON, URSULA: Optics of triclinic adularia ... *1879*

CHAPPELL, W. M., DURHAM, J. W. AND SAVAGE, D. E.: Rhinoceros mold in basalt ... *1949*

Chemical analyses
Hawaiian islands. By G. A. Macdonald ... 1541

— formula of kempite. By A. F. Rogers ... *1944*

CHENOWETH, P. A.: Statistical treatment of facies change. *1967*

CHESTERMAN, C. W.: Dike complex in the Turtle Mountains, eastern San Bernardino County, California ... *1937*

CLABAUGH, S. E.: Eudialyte and eucolite from southern New Mexico ... *1879*

CLARK, JOHN: Geologic reconnaissance in central Asia ... *1880*

Clay-mineral composition of some sediments from the Pacific Ocean off the California Coast and the Gulf of California. By R. E. Grim, Robert S. Dietz, and W. F. Bradley ... 1785

CLEMENTS, THOMAS: Leonardo da Vinci as a geologist ... *1937*

Climatic changes in nonglaciated areas, Physical effects of. By H. T. U. Smith ... 1485

Climatology of the Pleistocene. By Helmut Landsberg ... 1437

CLINE, L. M., AND BURMA, B. H.: Paleoecological study of the Pennsylvanian Exline limestone of Iowa and Missouri ... *1880*

Coal Creek quartzite, Jefferson and Boulder counties, Colorado. By G. D. Fraser ... *1960*

Colorado, Geology of the McCoy area, Eagle and Routt counties. By H. F. Donner ... 1215

— Rockies, Valley widening processes in the. By B. A. Tator ... 1771

Cone-axis diffraction patterns. By D. J. Fisher ... *1888*

Conglomerates of western Trans-Pecos Texas and their relation to a tectonic boundary. By J. F. Smith, Jr. and C. C. Albritton, Jr. ... *1921*

CONYBEARE, C. E. B., AND CAMPBELL, C. D.: Petrology of the red radioactive zones north of Goldfields, Saskatchewan ... *1881*

COOMBS, H. A.: Granitization in the Swauk formation near Wenatchee, Washington ... 192

Correlation of Pliocene mammalian faunas of Nevada. By J. R. Macdonald ... 195

— — — Ogallala caprock caliche with Reynosa caliche of Gulf Coastal Plain. By W. A. Price ... 193

Cretaceous, Baja California. By W. P. Popenoe and Gordon Weir ... 194

CRIPPEN, R. A.: Nephrite jade and associated rocks of the Cape San Martin region, Monterey County, California ... 192

Critical environments of deposition—shelf, slope, and bottom—and criteria for their recognition. By J. L. Rich ... 192

CROSS, A. T.: Sedimentary cycles in the Dunkard and Monongahela series of Ohio ... 192

Crystal Spring formation, southern Death Valley area, California. By L. A. Wright ... 194

Crystallization differentiation
Hawaiian islands. By G. A. Macdonald ... 154

Cubic pseudomorphs of quartz after halite in petrified wood. By L. W. Staples ... 194

Currents in submarine canyons. By F. P. Shepard ... 139

CURRY, H. D.: "Turtlebacks" of central Black Mountains, Death Valley, California ... 192

Cycle of deposition in the Salado formation of the Permian of New Mexico and Texas. By W. B. Lang ... 193

Cyphaspis and other trilobites from Oklahoma. By E. A. Frederickson ... 188

Dacites from Laughlin Peak, Colfax County, New Mexico. By Helen Stobbe ... 192

DREVES, E. S., Jr.: Biogeography of the Pleistocene ... 1313

DEJNOZKA, LADISLAV (With L. W. STROCK): Spectrochemical analysis of rocks ... 197

DELAVAULT, R. E. (With H. V. Warren): Gold and silver content of some trees and horsetails in British Columbia ... 194

Desert Hot Springs earthquake of December 4, 1948. By C. F. Richter ... 195

Development and use of multiple packers by the Bureau of Reclamation for ground-water observation in engineering geology. By W. H. Irwin, T. P. Ahrens, A. C. Barlow and E. D. Rhoades ... 189

— of Lake Superior soft iron ore from metamorphosed iron formations. By S. A. Tyler ... 1101

Diastrophism
Frequency and periodicity of orogenetic movements. By L. M. R. Rutten ... 175

DIETZ, R. S., AND BUFFINGTON, E. C.: Sea-floor investigations in the north Pacific and Bering Sea ... 182

— (With A. CARSOLA and R. D. RUSSELL): Submarine geology of two northeast Pacific sea mounts ... 187

— (With R. E. GRIM and W. F. BRADLEY): Clay-mineral composition of some sediments from the Pacific Ocean off the California Coast and the Gulf of California ... 178

Diffusion of ions through intergranular spaces in water-saturated rocks. By R. M. Garrels, R. M. Dreyer, and A. L. Howland ... 189

Dike complex in the Turtle Mountains, eastern San Bernardino County, California. By C. W. Chesterman ... 193

Directional characteristics of strain seismograph parts. By Hugo Benioff ... 193

Directions of orogenic stress. By Peter Misch ... 189

Discussion of the current practice in the design of structures to resist earthquakes. By G. W. Housner ... 189

— — tripartite microseismic measurements. By L. D. Leet ... 193

Disorder in sulphides. By A. H. Frueh, Jr. ... 188

Distribution, occurrence, and resources of sub-bitumi-

nous coal and lignite in the western United States. By R. P. Bryson ... *1875*
Diverse concepts of the Amsden formation. By J. S. Williams ... *1928*
Diving, Terrestrial topography of submarine canyons revealed by. By F. P. Shepard ... 1597
Dix, C. H., Geldart, L. P., Ingram, R. and Faessler, C. W.: Long period acceleration measurements ... *1953*
Doeglas, D. J., Koning, A. and Germeraad, J. H.: Tidal-flat environment ... *1882*
Dolomite crystals of teruel habit from Lake Arthur, Chavez County, New Mexico. By A. F. Rogers ... *1943*
Donner, H. F.: Geology of the McCoy area, Eagle and Routt counties, Colorado ... 1215
Dorr, J. Van H., II, and Guild, P. W.: Notes on the iron ores of central Minas Gerais, Brazil ... *1883*
Dort, Wakefield, Jr.: Glaciation of the Coeur d'Alene mining district, Idaho ... *1883*
Downs, Theodore: A Pleistocene avifauna from Kansas and its environment ... *1949*
Drainage Patterns. By C. W. Carlston ... *1967*
Dreyer, R. M., Howland, A. L., and Garrels, R. M.: Wall-rock replacement by oxidized copper minerals ... *1884*
— (With R. M. Garrels and A. L. Howland): Diffusion ions through intergranular spaces in water-saturated rocks ... 1809
— (With R. M. Garrels and A. L. Howland): Precipitation of basic copper ... *1890*
Dune forms in western Nebraska. By H. T. U. Smith ... *1920*
Durham, J. W.: Pacific Coast Tertiary marine climates ... *1884*
— (With W. M. Chappell and D. E. Savage): Rhinoceros mold in basalt ... *1949*

Earthquakes
Fault origin of oceanic deeps. By Hugo Benioff ... 1837
— and rock creep. By Hugo Benioff ... *1936*
East-west cross section through the southern Permian basin of west Texas. By West Texas Geological Society, Stratigraphic Committee ... *1928*
Easton, W. H.: Mississippian cuneate corals ... *1950*
Eckel, E. B.: Engineering Geology Branch, U. S. Geological Survey ... *1884*
El Salvador, Central America, Reconnaissance geology and vertebrate paleontology of. By R. A. Stirton and W. K. Gealey ... 1731
Electronic seismography, By J. A. Volk and Florence Robertson ... *1958*
Elevations of some Lake Lahontan shore lines. By G. M. Stanley ... *1945*
Ellis, M. W. (With Mackenzie Gordon and J. I. Tracey): Field relations of Arkansas bauxite deposits ... *1891*
Ellison, S. P., Jr.: Subsurface Woodford black shale of west Texas and southeast New Mexico ... *1885*
Elms, M. A. (With S. S. Goldich): Stratigraphy and petrology of the Buck Hill quadrangle, Texas ... 1133
Engel, A. E. J. (With R. H. Jahns): Pliocene breccias in the Avawatz Mountains, San Bernardino County, California ... *1940*
Engel, K. H.: Spontaneous growth of radially constructed crystal aggregates from supercooled melts ... *1968*
Engineering Geology Branch, U. S. Geological Survey. By E. B. Eckel ... *1884*
— — of the Isabella project, California. By R. C. Treasher *1946*
— petrography of loess. By R. C. Mielenz, W. Y. Holland and M. E. King ... *1909*
Ensimatic and ensialic geosynclines. By F. G. Wells ... *1927*
Eocene and Oligocene formations in the western Great Basin. By D. I. Axelrod ... *1935*
Eolian phenomena. By H. T. U. Smith ... 1485
Erosion, Glacial. By C. D. Holmes ... 1429
Eudialyte and eucolite from southern New Mexico. By S. E. Clabaugh ... *1879*
Europe, Trends in Glaciology in. By Henri Bader ... 1309
Evernden, J. (With Perry Byerly): First motion from deep and shallow rocks ... *1953*
Ewing, Maurice: Seismic studies in ocean basins ... *1885*
—, Tolstoy, Ivan, and Press, Frank: Proposed tsunami warning system ... *1954*
— (With Ivan Tolstoy): North Atlantic hydrography and the Mid-Atlantic Ridge ... 1527
— (— Frank Press and Ivan Tolstoy): Airy phase of shallow-focus submarine earthquakes ... *1956*
— (— Ivan Tolstoy and Frank Press): "T" phase of shallow-focus submarine earthquakes ... *1957*
— *et al.*: Seismic refraction measurements in the Atlantic Ocean Basin ... 1303

Faessler, C. W. (With C. H. Dix, *et al.*): Long period acceleration measurements ... *1953*
Fairbairn, H. W.: Synthetic quartzite ... *1886*
Faul, H. and Roberts, W. A.: New fossil footprints from Colorado ... *1886*
— Tittle, C. W. and Goodman, Clark: Neutron logging of drill holes ... *1886*
— (With C. W. Tittle and Clark Goodman): Nuclear radiations in well logging ... *1923*
Fault pattern of south-central Oregon. By I. S. Allison ... *1935*
Favorable ore zones of the Northport district, northeastern Washington. By C. D. Campbell ... *1878*
Features of the Seward Firn field, St. Elias Range, Canada. By R. P. Sharp ... *1918*
Feth, J. H.: Structural reconnaissance of the Red Rock quadrangle, Arizona ... *1887*
Field relations of Arkansas bauxite deposits. By Mackenzie Gordon, J. I. Tracey and M. W. Ellis ... *1891*
Fields, R. W. (With D. Henao-Londano): Honda formation of the upper Magdalena River basin, Colombia, S. A. ... *1894*
Finley, Robert, Jr. (With A. G. Fischer): Microstructure of some Pennsylvanian nautiloids ... *1887*
First motion from deep and shallow rocks. By Perry Byerly and J. Evernden ... *1953*
Fischer, A. G. and Finley, Robert, Jr.: Microstructure of some Pennsylvanian nautiloids ... *1887*
Fisher, D. J.: Cone-axis diffraction patterns ... *1888*
Flint, D. E.: Natural limestone walls of Okinawa ... *1968*
— (With R. A. Saplis): Ramparts on the elevated atoll of Kita Daito Jima ... *1974*
Flint, R. F., *Chairman:* Pleistocene Research ... 1305
Flower, R. H.: Structural history of the Hudson Valley *1969*
Folk, R. L.: Petrology of Lower Ordovician cherts in central Pennsylvania ... *1969*
Former marine shore lines of the Gaviota quadrangle, Santa Barbara County, California. By J. E. Upson ... *1925*
Fossil plants from Santee Valley, South Carolina. By W. E. Berry ... *1874*
Fowler-Billings, Katharine: Geology of the Monadnock region of New Hampshire ... 1249
Fraser, G. D.: Coal Creek quartzite, Jefferson and Boulder counties, Colorado ... *1960*
Frautschy, J. D.: Use of a variable-field electromagnetic mineral separator in sedimentary petrography ... *1888*
Frederickson, E. A.: Cyphaspis and other trilobites from Oklahoma ... *1888*
Frequency and periodicity of orogenetic movements. By L. M. R. Rutten ... 1755
—distribution analysis of slopes. By A. N. Strahler ... *1975*
Friedman, I.: Liquid immiscibility in the Na_2O–SiO_2–H_2O system. Preliminary data on the Na_2O–SiO_2–Al_2O_3–H_2O system ... *1889*

FRIES, CARL, JR. (With C. H. BEHRE, JR.): Geomorphic events of east-central Mexico ... *1873*
FRONDEL, CLIFFORD: Survey of the mineralogy of uranium ... *1889*
Frost action. By H. T. U. Smith ... 1485
FRUEH, A. H., JR.: Disorder in sulphides ... *1889*

GABELMAN, J. W.: Laramide structure and igneous activity of the Fulford and Brush Creek mining districts, Colorado ... *1960*
GALBRAITH, F. W.: Thrust faulting in the Empire Mountains, southeastern Arizona ... *1889*
GARRELS, R. M., DREYER, R. M., AND HOWLAND, A. L.: Diffusion of ions through intergranular spaces in water-saturated rocks ... 1809
—, HOWLAND, A. L. AND DREYER, R. M.: Precipitation of basic copper ... *1890*
— (With R. M. DREYER and A. L. HOWLAND): Wall-rock replacement by oxidized copper minerals ... *1884*
GATES, OLCOTT: Geology of the west side of the Gore Range near Radium, Colorado ... *1962*
GEALEY, W. K. (With R. A. STIRTON): Reconnaissance geology and vertebrate paleontology of El Salvador, Central America ... 1731
GELDART, L. P. (With C. H. DIX, *et al.*): Long period acceleration measurements ... *1953*
General aspects of disorder in minerals. By M. J. Buerger. *1876*
— geology of the Big Bend National Park, Texas. By R. A. Maxwell and J. T. Lonsdale ... *1908*
Genetic lines in California Cretaceous mollusks. By W. P. Popenoe ... *1951*
Geologic mapping in the United States. By Leona Boardman ... 1125
— reconnaissance in central Asia. By John Clark ... *1880*
Geological and botanical study of the Brandon lignite and its significance in coal petrology. By E. S. Barghoorn. *1872*
— — related activities in the Bureau of Reclamation, July 1948–July 1949. By Roger Rhoades ... *1916*
— features of North Dakota lignites. By W. B. Rose ... *1917*
— mapping by the U. S. Geological Survey in the Great Smoky Mountains National Park. By J. B. Hadley ... *1970*
— problems connected with flood control in the Central Valley of California. By C. P. Holdredge ... *1939*
— reconnaissance of the Island of Margarita, Venezuela, Part 1. By H. H. Hess and J. C. Maxwell ... 1857
Geology and Pleistocene Research, Submarine. By F. B Phleger ... 1457
— — soil science, Interrelations of Pleistocene. By James Thorp ... 1517
Geology of Bright Angel quadrangle, Arizona. By J. H. Maxson ... *1963*
— — Helvetia mining district, Pima County, Arizona. By V. H. Johnson ... *1900*
— — Irwin district of Colorado. By A. A. Socolow ... *1921*
— — Manzanita and North Manzano Mountains, New Mexico. By Parry Reiche ... 1183
— — McCoy area, Eagle and Routt counties, Colorado. By H. F. Donner ... 1215
— — Monadnock region of New Hampshire. By Katharine Fowler-Billings ... 1249
— — northern part of the Sangre de Cristo Mountains, Colorado. By C. R. Butler ... *1959*
— — Shasta Valley and the adjacent Cascades, northeastern California. By Howel Williams ... *1947*
— — Silver Lake talc area, San Bernardino County, California. By L. A. Wright ... *1932*
— — west side of the Gore Range near Radium, Colorado. By Olcott Gates ... *1962*
— — Whiskey Gap-Muddy Gap and Ferris Mountains region, Wyoming. By E. L. Heisey, D. E. Lawson and R. J. Weimer ... *1961*
Geometry of triclinic adularia. By Fritz Laves ... *1903*
Geomorphic events of east-central Mexico. By C. H. Behre, Jr. and Carl Fries, Jr. ... *1873*
GERMERAAD, J. H. (With D. J. DOEGLAS and A. KONING): Tidal-flat environment ... *1882*
GIANELLA, V. P.: Verdi, Nevada, earthquake of December 29, 1948 ... *1938*
Glacial erosion and sedimentation. By C. D. Holmes ... 1439
— geology of the west-central Wind River Mountains, Wyoming. By G. W. Holmes ... *1896*
— molding of the Gulf of Maine. By G. H. Chadwick ... *1967*
Glaciation, Alpine. By L. L. Ray ... 1473
Glaciation in the southern Wind River Mountains, Montana. By J. H. Moss ... *1911*
— of the Coeur d'Alene mining district, Idaho. By Wakefield Dort, Jr. ... *1883*
Glaciological studies on the Seward ice field, Canada, during 1948. By R. P. Sharp ... *1944*
Glaciology in Europe, Trends in. By Henri Bader ... 1309
Gogebic range, Occurrence and origin of ore bodies on. By S. A. Tyler ... 1101
Gold and silver content of some trees and horsetails in British Columbia. By H. V. Warren and R. E. Delavault ... *1947*
Golden Valley formation of North Dakota. By W. E. Benson ... *1873*
GOLDICH, S. S., AND ELMS, M. A.: Stratigraphy and petrology of the Buck Hill quadrangle, Texas ... 1133
GOLDMAN, MARCUS: Petrology of bauxite surrounding a boulderlike core of kaolinized nepheline syenite in Arkansas ... *1890*
GOLDSMITH, J. R.: Significance of gallium and germanium replacements in synthetic feldspars ... *1891*
GOODMAN, CLARK (With HENRY FAUL and C. W. TITTLE): Neutron logging of drill holes ... *1886*
— (— C. W. TITTLE and HENRY FAUL): Nuclear radiations in well logging ... *1923*
GOODSPEED, G. E.: Mineralization related to granitization ... *1938*
—: Rheomorphic breccias ... *1891*
GORDON, MACKENZIE, JR., TRACEY, J. I. AND ELLIS, M. W.: Field relations of Arkansas bauxite deposits ... *1891*
GRAHAM, J. J.: Occurrence of a questionable Elphidium in the early Tertiary of California ... *1910*
Granitization in the Swauk formation near Wenatchee, Washington. By H. A. Coombs ... *1937*
GREENE, K. T. (With R. C. MIELENZ, *et al.*): Materials for pozzolan ... *1944*
GRIFFITTS, M. O.: Zonation and correlation of the Pierre shale of Colorado ... *1961*
GRIM, R. E., DIETZ, R. S., AND BRADLEY, W. F.: Clay-mineral composition of some sediments from the Pacific Ocean off the California Coast and the Gulf of California ... 1785
Ground vibrations from explosions. By B. F. Howell, Jr. ... *1954*
GUDE, A. J.: Simple method of preparing crystal models ... *1961*
GUILD, P. W. (With J. VAN H. DORR, II): Notes on the iron ores of central Minas Gerais, Brazil ... *1893*
Gulf of California, Clay-mineral composition of some sediments from the Pacific Ocean off the California Coast and. By R. E. Grim, *et al.* ... 1785
GUTENBERG, BENO: Approximations in geophysics ... *1894*
—: Properties of the earth's crust beneath the oceans ... *1892*
GUTSCHICK, R. C.: Redwall limestone along the southwest margin of the Colorado Plateau, Arizona ... *1898*

HADLEY, J. B.: Geological mapping by the U. S. Geological Survey in the Great Smoky Mountains National Park ... *1970*
HAM, W. E.: Stratigraphy of the Arbuckle limestone, Arbuckle Mountains, Oklahoma ... *1893*
HAMILTON, G. R. (With Maurice Ewing *et al.*): Seismic refraction measurements in the Atlantic Ocean Basin. 1303
HARRINGTON, J. W.: Structural analysis of the west border of the Durham Triassic basin ... *1893*
HAUCHECORNITE. By M. A. Peacock ... *1913*
Hawaiian petrographic province. By G. A. Macdonald. . 1541
HEISEY, E. L., LAWSON, D. E., AND WEIMER, R. J.: Geology of Whiskey Gap-Muddy Gap and Ferris Mountains region, Wyoming ... *1961*
HENAO-LONDANO, D. AND FIELDS, R. W.: Honda formation of the upper Magdalena River basin, Colombia, S. A. ... *1894*
HENBEST, LLOYD: Significance of explosive evolution for diastrophic division of earth history ... *1894*
HENDRICKS, LEO: Recognition of the Lower Ordovician formations in the subsurface of central Texas ... *1895*
HERSEY, J. B. (With MAURICE EWING *et al.*): Seismic refraction measurements in the Atlantic Ocean Basin. . 1303
HESS, H. H. AND J. C. MAXWELL: Geological reconnaissance of the Island of Margarita, Venezuela, Part 1. . 1857
HEWETT, D. F.: Kingston thrust fault, Inyo, San Bernardino counties, California ... *1895*
HIBBARD, C. W.: Pleistocene Vertebrate Paleontology in North America ... 1417
HIESTAND, T. C. (With H. E. SUMMERFORD and E. E. SCHIECK): Lithofacies problems, Newcastle sandstone, Mush Creek and Skull Creek area, Weston County, Wyoming ... *1965*
High-temperature albite. By O. F. Tuttle and N. L. Bowen ... *1925*
HILDEBRAND, F. A.: Orbicular tinguaite dikes near Bryant, Saline County, Arkansas ... *1896*
Historical inferences from a recent exposure of the Haywards fault, near Niles, California. By G. D. Louderback ... *1955*
History of a feldspar crystal. By S. J. Shand ... 1213
—— seismological station at Fresno, California. By V. C. McKim ... *1956*
HOARE, J. M. (With R. E. WALLACE, *et al.*): Thermal metamorphism in the central Kuskokwim region, southwestern Alaska ... *1946*
HOLDREDGE, C. P.: Geological problems connected with flood control projects in the Central Valley of California ... *1939*
HOLKE, K. A. (With R. J. Bailly): Microscope and refractometer for infra-red light ... *1871*
HOLLAND, H. D. AND KULP, J. L.: Alpha activity of rocks and sediments by scintillation counting ... *1896*
HOLLAND, W. Y. (With R. C. MIELENZ and M. E. KING): Engineering petrography of loess ... *1909*
HOLMES, C. D.: Glacial erosion and sedimentation ... 1429
HOLMES, G. W.: Glacial geology of the west-central Wind River Mountains, Wyoming ... *1896*
Honda formation of the upper Magdalena River basin, Colombia, S. A. By D. Henao-Londano and R. W. Fields ... *1894*
HONKALA, F. S.: Stratigraphy of the Centennial region, Beaverhead County, Montana ... *1897*
HORBERG, LELAND: Intersecting minor ridges on the Lake Agassiz Plain, North Dakota ... *1970*
HOUSNER, G. W.: Discussion of the current practice in the design of structures to resist earthquakes ... *1954*
HOWELL, B. F., JR.: Ground vibrations from explosions. . *1954*
HOWLAND, A. L. (With R. M. DREYER and R. M. GARRELS): Wall-rock replacement by oxidized copper minerals ... *1884*
— (— R. M. GARRELS and R. M. DREYER): Diffusion of ions through intergranular spaces in water-saturated rocks ... 1809
— (— — — —): Precipitation of basic copper ... *1890*
HURLBUT, C. S., JR.: Beryl at Mt. Mica, Maine ... *1897*
HUTTON, C. O.: Occurrence of leonhardite ... *1939*
Hydrography of North Atlantic. By Ivan Tolstoy and Maurice Ewing ... 1527
Hydroxyl in minerals. By W. D. Keller and E. E. Pickett. *1901*

Igneous rocks of Buck Hill quadrangle, Texas. By S. S. Goldich and M. A. Elms ... 1133
— — — Hawaiian islands. By G. A. Macdonald ... 1541
— — — Manzanita and North Manzano Mountains, New Mexico. By Parry Reiche ... 1183
Impulsive hydrodynamics of a partially filled cylindrical tank as well as of a cylinder surrounded by a finite depth of fluid. By L. S. Jacobsen ... *1955*
Indications of a large coelacanth fish in the Permian Vale formation of Texas. By J. A. Wilson ... *1930*
INGRAM, R. (With C. H. DIX, *et al.*) Long period acceleration measurements ... *1953*
INMAN, D. L.: Sorting of sediments in the light of fluid mechanics ... *1940*
Interrelations of Pleistocene geology and soil science. By James Thorp ... 1517
Intersecting minor ridges on the Lake Agassiz Plain, North Dakota. By Leland Horberg ... *1970*
Investigations in the subsurface geology of the Maryland coastal plain. By R. M. Overbeck ... *1972*
IRELAND, H. A.: Pleistocene physiography and sedimentation in the Caddo Canyons of Oklahoma ... *1898*
Iron formation and associated rocks of the Iron River district, Michigan. By H. L. James ... *1899*
IRWIN, W. H., AHRENS, T. P., BARLOW, A. C. AND RHOADES, E. D.: Development and use of multiple packers by the Bureau of Reclamation for ground-water observation in engineering geology ... *1898*

JACOBS, E. C.: Physical features of Vermont ... *1970*
JACOBSEN, L. S.: Impulsive hydrodynamics of a partially filled cylindrical tank as well as of a cylinder surrounded by a finite depth of fluid ... *1955*
Jadeite problem. By H. S. Yoder, Jr. ... *1933*
JAFFE, H. W.: Role of yttrium and other minor elements in the garnet group ... *1899*
JAHNS, R. H.: Lithium-bearing pegmatites near Wickenburg, Arizona ... *1899*
JAHNS, R. H. AND ENGEL, A. E. J.: Pliocene breccias in the Avawatz Mountains, San Bernardino County, California ... *1940*
JAMES, H. L.: Iron formation and associated rocks of the Iron River district, Michigan ... *1899*
JENKS, W. F.: Triassic to Tertiary stratigraphy near Cerro de Pasco, Peru ... *1900*
JOHNSON, J. H.: Permian calcareous algae from the Apache Mountains, Texas ... *1900*
JOHNSON, R. B.: Upper Devonian opiurans in central New York ... *1971*
JOHNSON, V. H.: Geology of the Helvetia mining district, Pima County, Arizona ... *1900*
June Lake district, California, Quaternary geology of. By W. C. Putnam ... 1281

KAY, MARSHALL: Pleistocene lakes in the Mohawk Valley, New York ... *1971*

Keene-Brattleboro area, New Hampshire-Vermont, Structure and metamorphism of. By G. E. Moore, Jr.. 1613
KELLER, W. D. AND PICKETT, E. E.: Hydroxyl in minerals ... 1901
Kern Canyon fault, Kern County, California. By R. C. Treasher ... 1957
KERR, P. F.: Alteration features at Silver Bell, Arizona.. 1901
KIERSCH, G. A.: Some geologic factors in subterranean construction ... 1940
KING, M. E. (With R. C. MIELENZ and W. Y. HOLLAND): Engineering petrography of loess ... 1909
— (— — *et al.*): Materials for pozzolan ... 1964
KING, P. B., AND MCKEE, E. M.: Terrain diagrams of the Philippine Islands ... 1829
Kingston thrust fault, Inyo, San Bernardino counties, California. By D. F. Hewett ... 1895
KONING, A. (With D. J. DOEGLAS and J. H. GERMERAAD): Tidal-flat environment ... 1882
KOSANKE, R. M.: Review of coal research 1948–1949 ... 1901
KULP, J. L. AND CARR, D. R.: Surface area of deep-sea sediments ... 1902
— (With H. D. HOLLAND): Alpha activity of rocks and sediments by scintillation counting ... 1896
KUTINA, JAN: Scheme of the chemistry of the ore veins based on qualitative spectrographic analysis ... 1902

Lake Russell. By W. C. Putnam ... 1281
— Superior soft iron ore from metamorphosed iron formations, Development of. By S. A. Tyler ... 1101
Lacorocah metatuff member (new name) (Precambrian), New Mexico. By Parry Reiche ... 1183
LANCE, J. F.: Phylogenetic significance of some Pliocene horses from Mexico ... 1950
LANDES, K. K.: Metallurgical limestone reserves ... 1902
LANDSBERG, HELMUT: Climatology of the Pleistocene ... 1437
LANG, W. B.: Cycle of deposition in the Salado formation of the Permian of New Mexico and Texas ... 1903
LANGSTON, WANN, JR.: Permian amphibians from the Abo formation of New Mexico ... 1903
Laramide structure and igneous activity of the Fulford and Brush Creek mining districts, Colorado. By J. W. Gabelman ... 1960
LAVES, FRITZ: Geometry of triclinic adularia ... 1903
LAWSON, E. L. (With E. L. HEISEY and R. J. WEIMER): Geology of the Whiskey Gap-Muddy Gap and Ferris Mountains region, Wyoming ... 1961
LEET, L. D.: Discussion of tripartite microseismic measurements ... 1955
LEIGHTON, M. M. AND SCHAFFER, P. R.: Newly discovered extension of the Labradorean ice sheet into eastern Iowa during the Tazewell substage of the Wisconsin stage ... 1904
— AND WILLMAN, H. B.: Loess formations of Mississippi Valley ... 1904
Leonardo da Vinci as a geologist. By Thomas Clements.. 1937
LEROY, L. W.: Stratigraphic and micropaleontologic analysis of the Maqfi section Farafra Oasis, Western Desert of Egypt ... 1962
Leucoxene problem. By V. T. Allen ... 1870
LEVIN, S. B.: Physical analysis of polycomponent garnet ... 1905
Liquid immiscibility in the Na_2O–SiO_2–H_2O system. Preliminary data on the Na_2O–SiO_2–Al_2O_3–H_2O system. By I. Friedman ... 1889
Lithium-bearing pegmatites near Wickenburg, Arizona. By R. H. Jahns ... 1899
Lithofacies problems, Newcastle sandstone, Mush Creek and Skull Creek area, Weston County, Wyoming. By H. E. Summerford, E. E. Schieck and T. C. Hiestand ... 1965
Loess formations of Mississippi Valley. By M. M. Leighton and H. B. Willman ... 1904
LONGWELL, C. R.: Structure in the Arizona-Nevada boundary area ... 1905
LONSDALE, J. T. AND MAXWELL, R. A.: Petrology of Big Bend National Park, Texas ... 1906
— (With R. A. MAXWELL): General geology of the Big Bend National Park, Texas ... 1908
LOUDERBACK, G. D.: Historical inferences from a recent exposure of the Haywards fault near Niles, California ... 1955
LUNDELIUS, ERNEST: Note on a neural spine of a Permian armored amphibian ... 1906
LYNOTT, W. J.: Petrology of metamorphic rocks, migmatite, quartz diorite, and mineral deposits, Warn Bay-Tofino Inlet area, west coast Vancouver Island, British Columbia ... 1907

MACCLINTOCK, PAUL, AND PELTIER, L. C.: Wisconsin glacial stadia in New Jersey ... 1971
MACDONALD, G. A.: Hawaiian petrographic province.... 1541
MACDONALD, J. R.: Correlation of the Pliocene mammalian faunas of Nevada ... 1951
Manzanita Mountains, New Mexico, Geology of. By Parry Reiche ... 1183
Map of eolian deposits in North America. By James Thorp and H. T. U. Smith ... 1923
Mapping in the United States, Geologic. By Leona Boardman ... 1125
MARBLE, J. P.: Accuracy of the lead method for the absolute measurement of geologic ages ... 1907
Marfa Basin, Hudspeth County, Texas. By C. C. Albritton, Jr. and J. Fred Smith, Jr. ... 1919
Margarita, Venezuela, Geological reconnaissance of the Island of. By H. H. Hess and J. C. MAXWELL ... 1837
Marquette range, Occurrence and origin of ore bodies on. By S. A. Tyler ... 1101
MARSELL, R. E.: Basin Range faulting near Salt Lake City, Utah ... 1941
MASON, BRIAN AND VITALIANO, C. J.: Preliminary account of the naturally occurring antimony oxides.... 1907
Materials for pozzolan By R. C. Mielenz, K. T. Greene, N. C. Schieltz, and M. E. King ... 1964
MAXSON, J. H.: Geology of the Bright Angel quadrangle, Arizona ... 1963
MAXWELL, J. C. (With H. H. HESS): Geological reconnaissance of the Island of Margarita, Venezuela, Part 1.. 1837
MAXWELL, R. A. AND LONSDALE, J. T.: General geology of the Big Bend National Park, Texas ... 1909
— (With J. T. LONSDALE): Petrology of Big Bend National Park, Texas ... 1906
McCoy area, Eagle and Routt counties, Colorado, Geology of the. By H. F. Donner ... 1215
MCKEE, E. D.: Ripple marks of the Triassic Moenkopi formation ... 1941
—: Sedimentary basins of Arizona and adjoining areas.. 1908
MCKEE, E. M. (With P. B. KING): Terrain diagrams of the Philippine Islands ... 1829
MCKIM, V. C.: History of the seismological station at Fresno, California ... 1956
Mechanics of valley widening. By B. A. Tator ... 1771
Melonite from Boulder County, Colorado. By E. E. Wahlstrom ... 1909
MERRIAM, C. W.: Paleozoic rocks of Antelope Valley, Eureka County, Nevada ... 1942
Mesabi range, Occurrence and origin of ore bodies on. By S. A. Tyler ... 1101
Mesozoic boundaries and faunal changes. By C. L. Camp. 1877
— stratigraphy of southwestern Montana. By C. A. Moritz and L. L. Sloss ... 1910

Metallurgical limestone reserves. By K. K. Landes..... *1902*
Metamorphism
Regional
Wissahickon schist at Philadelphia. By Judith Weiss..... 1689
— of the Keene-Brattleboro area, New Hampshire-Vermont, Structure and. By G. E. Moore, Jr..... 1613
Method of obtaining a travel-time curve within a stripped earth. By V. C. Stechschulte, S. J..... *1957*
Microscope and refractometer for infra-red light. By R. J. Bailly and K. A. Holke..... *1871*
Microstructure of some Pennsylvanian nautiloids. By A. G. Fischer and Robert Finley, Jr..... *1887*
Mid-Atlantic Ridge. By Ivan Tolstoy and Maurice Ewing. 1527
Mid-Pennsylvanian pelycosaurs from Kansas. By F. E. Peabody..... *1913*
MIELENZ, R. C., HOLLAND, W. Y. AND KING, M. E.: Engineering petrography of loess..... *1909*
— *et al.*: Materials for pozzolan..... *1964*
MILTON, CHARLES: Nickel-copper-gold mineralogy at the Mackinaw Mine, Snohomish County, Washington..... *1909*
Mineralization related to granitization. By G. E. Goodspeed..... *1938*
Miniature cauldrons. By A. R. Addington..... *1935*
MISCH, PETER: Directions of orogenic stress..... *1909*
—: Structure, metamorphism and granitization in part of Okanogan County, north-central Washington.... *1942*
Mississippian cuneate corals. By W. H. Easton..... *1950*
Monadnock region of New Hampshire, Geology of. By Katharine Fowler-Billings..... 1249
MOORE, G. E., JR.: Structure and metamorphism of the Keene-Brattleboro area, New Hampshire-Vermont.. 1613
MORITZ, C. A., AND SLOSS, L. L.: Mesozoic stratigraphy of southwestern Montana..... *1910*
— (With L. L. SLOSS): Paleozoic stratigraphy of southwestern Montana..... *1920*
MORRIS, F. K.: Cause of an ice age..... *1910*
MOSS, J. H.: Glaciation in the southern Wind River Mountains, Montana..... *1911*
—: Possible new glacial substage in the middle Rocky Mountains..... *1972*
MOVIUS, H. L., JR.: Old-World Palaeolithic Archaeology. 1443
MURDOCH, JOSEPH: Perovskite from California..... *1911*
MURRAY, H. F.: Pennsylvanian stratigraphy of the McCoy area, Colorado..... *1965*

Natural clay grout in openwork gravel. By A. S. Cary.... *1878*
Natural limestone walls of Okinawa. By D. E. Flint..... *1968*
Nephrite jade and associated rocks of the Cape San Martin region, Monterey County, California. By R. A. Crippen..... *1938*
Neutron logging of drill holes. By Henry Faul, C. W. Tittle, and Clark Goodman..... *1886*
Nevada earthquakes. By Perry Byerly and Carl Romney. *1953*
New ceboid monkeys from the La Venta Late Miocene of Colombia, South America. By R. A. Stirton..... *1921*
— fossil footprints from Colorado. By A. Faul and W. A. Roberts..... *1886*
New Hampshire, Geology of the Monadnock region of. By Katharine Fowler-Billings..... 1249
—Vermont, Structure and metamorphism of the Keene-Brattleboro area. By G. E. Moore, Jr..... 1613
New Mexico, Geology of Manzanita and North Manzano Mountains. By Parry Reiche..... 1183
Newell, N. D.: Periodicity in invertebrate evolution..... *1911*
Newly discovered extension of the Labradorean ice sheet into eastern Iowa during the Tazewell substage of the Wisconsin stage. By M. M. Leighton and P. R. Schaffer..... *1904*
Nickel-copper-gold mineralogy at the Mackinaw Mine, Snohomish County, Washington. By Charles Milton. *1909*
Nontronite at Bingham, Utah. By Bronson Stringham and A. O. Taylor..... *1923*
North Atlantic hydrography and the Mid-Atlantic Ridge. By Ivan Tolstoy and Maurice Ewing..... 1527
North Manzano Mountains, New Mexico, Geology of. By Parry Reiche..... 1183
Note on a neural spine of a Permian armored amphibian. By Ernest Lundelius..... *1906*
Notes on iron ores of central Minas Gerais, Brazil. By J. Van H. Dorr, II, and P. W. Guild..... *1883*
Notes on permafrost problems in construction engineering. By D. S. Turner..... *1966*
Nuclear radiations in well logging. By C. W. Tittle, Clark Goodman and Henry Faul..... *1923*

OAKESCHOTT, G. B.: Titanomagnetite rocks of the western San Gabriel Mountains, California..... *1942*
Occurrence of leonhardite. By C. O. Hutton..... *1939*
— — questionable Elphidium in the early Tertiary of California. By J. J. Graham..... *1950*
Occurrence of Texan Permian ammonoids in Arizona. By Alexander Stoyanow..... *1946*
Oceanic deeps, Seismic evidence for the fault origin of. By Hugo Benioff..... 1837
Ojito stock (new name) (Precambrian), central New Mexico. By Parry Reiche..... 1183
Old-world Palaeolithic Archaeology. By H. L. Movius, Jr..... 1443
Older Precambrian structure in Arizona. By C. A. Anderson..... *1870*
Ontogenetic variation in Eponides Mexicanus (Cushman) By O. L. Bandy..... *1949*
Optics of triclinic adularia. By Ursula Chaisson..... *1879*
Orbicular tinguaite dikes near Bryant, Saline County, Arkansas. By F. A. Hildebrand..... *1896*
Origin of epithermal mineral deposits. By Harrison Schmitt..... *1918*
— — ruptured Eocene cobbles in the Bearpaw Mountains, Montana. By W. T. Pecora..... *1913*
Orogenetic movements, Frequency and periodicity of. By L. M. R. Rutten..... 1755
OSTERWALD, F. W.: Relation of structure to petrology in the northern Bighorn Mountains, Wyoming..... *1965*
OVERBECK, R. M.: Investigations in the subsurface geology of the Maryland coastal plain..... *1972*

Pacific Coast Tertiary marine climates. By J. W. Durham. *1884*
— Ocean off the California coast and the Gulf of California, Clay-mineral composition of some sediments from. By R. E. Grim, *et al.*..... 1785
PAGE, B. M.: Structure of the Candelaria district, Mineral County, Nevada..... *1943*
Paleoecological study of the Pennsylvanian Exline limestone of Iowa and Missouri. By L. M. Cline and B. H. Burma..... *1880*
Paleogeology of the Panhandle of Texas. By Robert Roth..... 1671
Palaeolithic Archaeology, Old-world. By H. L. Movius, Jr..... 1443
Paleontology
Reconnaissance geology and vertebrate paleontology of El Salvador, Central America. By R. A. Stirton and W. K. Gealey..... 1731
— in North America, Pleistocene Vertebrate. By C. W. Hibbard..... 1417
Paleozoic rocks of Antelope Valley, Eureka County, Nevada. By C. W. Merriam..... *1942*

Paleozoic stratigraphy of southwestern Montana. By L. L. Sloss and C. A. Moritz ... *1920*
Panhandle of Texas, Paleogeology of. By Robert Roth ... 1671
PARKS, B. C.: Petrography of American lignites ... *1912*
PARRY, V. F.: Production, classification and utilization of western United States coals ... *1912*
PEABODY, F. E.: Mid-Pennsylvanian pelycosaurs from Kansas ... *1913*
PEACOCK, M. A.: Hauchecornite ... *1913*
PECORA, W. T.: Origin of ruptured Eocene cobbles in the Bearpaw Mountains, Montana ... *1913*
PELTIER, L. C. (With Paul MacClintock): Wisconsin glacial stadia in New Jersey ... *1971*
Pennsylvania, Wissahickon schist at Philadelphia. By Judith Weiss ... 1689
Pennsylvanian stratigraphy of the McCoy area, Colorado. By H. F. Murray ... *1965*
Peridotite body in the Laramie Mountains, Wyoming. By John Albanese ... *1959*
Periodicity in invertebrate evolution. By N. D. Newell ... *1911*
— — vertebrate evolution. By G. G. Simpson ... *1919*
— of orogenetic movements, Frequency and. By L. M. R. Rutten ... 1755
Permian amphibians from the Abo formation of New Mexico. By Wann Langston, Jr. ... *1903*
— calcareous algae from the Apache Mountains, Texas. By J. H. Johnson ... *1900*
Perovskite from California. By Joseph Murdoch ... *1911*
Petrogenesis of Hawaiian rocks. By G. A. Macdonald ... 1541
Petrographic province, Hawaiian. By G. A. Macdonald ... 1541
Petrography of American lignites. By B. C. Parks ... *1912*
Petrology of bauxite surrounding a boulderlike core of kaolinized nepheline syenite in Arkansas. By Marcus Goldman ... *1890*
— — Big Bend National Park, Texas. By J. T. Lonsdale and R. A. Maxwell ... *1906*
— — Buck Hill quadrangle, Texas. By S. S. Goldich and M. A. Elms ... 1133
— — Hawaiian Islands. By G. A. Macdonald ... 1541
— — Lower Ordovician cherts in central Pennsylvania. By R. L. Folk ... *1969*
— — metamorphic rocks, migmatite, quartz diorite, and mineral deposits, Warn Bay-Tofino Inlet area, west coast Vancouver Island, British Columbia. By W. J. Lynott ... *1907*
— — red radioactive zones north of Goldfields, Saskatchewan. By C. E. B. Conybeare and C. D. Campbell ... *1881*
PETTERSSON, HANS: Submarine geology: Swedish deep sea expedition, 1947–1948 ... *1914*
Philadelphia, Penna., Wissahickon schist at. By Judith Weiss ... 1689
Philippine Islands, Terrain diagrams of. By P. B. King and E. M. McKee ... 1829
PHOENIX, D. A. (With C. C. ALBRITTON, Jr. *et al.*): Structural features associated with lead and zinc ores of the Goodsprings district, Nevada ... *1869*
Photography in La Jolla submarine canyons. By F. P. Shepard ... 1597
PHLEGER, F. B: Submarine geology and Pleistocene Research ... 1457
Phylogenetic significance of some Pliocene horses from Mexico. By J. F. Lance ... *1950*
Physical analysis of polycomponent garnet. By S. B. Levin ... *1905*
— **effects of Pleistocene climatic changes in nonglaciated areas.** By H. T. U. Smith ... 1485
— features of Vermont. By E. C. Jacobs ... *1970*
PICKETT, E. E. (With W. D. KELLER): Hydroxyl in minerals ... *1901*
PINCUS, H. J.: Quantitative comparative study of fractures in gneisses and overlying sediments of northern New Jersey ... *1977*
Plans for the earthquake engineering research institute. By J. A. Blume ... *1953*
Pleistocene
Biogeography of. By E. S. Deevey, Jr. ... 1385
Climatology of. By Helmut Landsberg ... 1427
Pleistocene avifauna from Kansas and its environment. By Theodore Downs ... *1949*
— climatic changes in nonglaciated areas, Physical effects of. By H. T. U. Smith ... 1485
— geology and soil science. By James Thorp ... 1377
— geology of the upper Teton River, central Montana. By J. P. Schafer ... *1974*
— lakes in the Mohawk Valley, New York. By Marshall Kay ... *1971*
— mammals of El Salvador
Reconnaissance geology and vertebrate paleontology of El Salvador, Central America. By R. A. Stirton and W. K. Gealey ... 1721
— physiography and sedimentation in the Caddo Canyons of Oklahoma. By H. A. Ireland ... *1970*
— **Research.** By R. F. Flint, Chairman ... 1386
— —, Submarine geology and. By F. B Phleger ... 1440
Pleistocene stratigraphy, Problems of. By L. L. Ray ... 1465
Pleistocene Vertebrate Paleontology in North America. By C. W. Hibbard ... 1437
Pliocene breccias in the Avawatz Mountains, San Bernardino County, California. By R. H. Jahns and A. E. J. Engel ... *1940*
POPENOE, W. P.: Genetic lines in California Cretaceous mollusks ... *1951*
— AND WEIR, GORDON: Cretaceous, Baja California ... *1943*
Possible new glacial substage in the middle Rocky Mountains. By J. H. Moss ... *1972*
PRAY, L. C.: Pre-Abo deformation in the Sacramento Mountains, New Mexico ... *1944*
Pre-Abo deformation in the Sacramento Mountains, New Mexico. By L. C. Pray ... *1944*
Pre-Equus horses from Goleta (Morelia) Michoacan, Mexico. By A. R. V. Arellano and Ernesto Azcon ... *1971*
Pre-Pennsylvanian rocks of northern Rhode Island. By A. W. Quinn ... *1972*
Precambrian of a district in central New Mexico. By Parry Reiche ... 1183
Precipitation of basic copper. By R. M. Garrels, A. L. Howland and R. M. Dreyer ... *1969*
Preliminary account of the naturally occurring antimony oxides. By Brian Mason and C. J. Vitaliano ... *1987*
Preliminary report on geology of Popocatepetl, Mexico. By S. E. White ... *1976*
— — — Ostracoda in bottom samples and cores of northwestern Gulf of Mexico. By W. T. Rothwell, Jr. ... *1978*
— — — system leucite–SiO_2–FeO. By Edwin Roedder ... *1967*
— — — Torrejonian faunule from near Angels Peak, San Juan Basin, New Mexico. By R. W. Wilson ... *1930*
PRESS, FRANK, EWING, MAURICE, AND TOLSTOY, IVAN: Airy phase of shallow-focus submarine earthquakes ... *1956*
— (With MAURICE EWING AND IVAN TOLSTOY): Proposed tsunami warning system ... *1964*
— (— IVAN TOLSTOY and MAURICE EWING): "T" phase of shallow-focus submarine earthquakes ... *1937*
— (— MAURICE EWING *et al.*): Seismic refraction measurements in the Atlantic Ocean Basin ... *1938*
PRICE, W. A.: Correlation of Pliocene Ogallala caprock caliche with Reynosa caliche of Gulf Coastal Plain ... *1976*
Probable Illinoian age of part of the Missouri River. By C. R. Warren ... *1928*

Problems of Pleistocene stratigraphy. By L. L. Ray..... 1463
Production, classification and utilization of western United States coals. By V. F. Parry..... *1912*
Properties of the earth's crust beneath the oceans. By B. Gutenberg..... *1892*
PUTNAM, W. C.: Quaternary geology of the June Lake district, California..... 1281

Quantitative comparative study of fractures in gneisses and overlying sediments of northern New Jersey. By H. J. Pincus..... *1977*
Quaternary geology of the June Lake district, California. By W. C. Putnam..... 1281
QUINN, A. W.: Pre-Pennsylvanian rocks of northern Rhode Island..... *1972*

RAITT, R. W.: Studies of ocean-bottom structure off Southern California with explosive waves..... *1915*
Ramparts on the elevated atoll of Kita Daito Jima. By R. A. Saplis and D. E. Flint..... *1974*
RAY, L. L.: Alpine glaciation..... 1475
—: Problems of Pleistocene stratigraphy..... 1463
Recent results of suboceanic geology and major earth problems. By W. H. Bucher..... *1876*
Recognition of the Lower Ordovician formations in the subsurface of central Texas. By Leo Hendricks..... *1895*
Reconnaissance geology and vertebrate paleontology of El Salvador, Central America. By R. A. Stirton and W. K. Gealey..... 1731
Redwall limestone along the southwest margin of the Colorado Plateau, Arizona. By R. C. Gutschick..... *1893*
Regional gravity study of the Appalachian Mountain system. By G. P. Wollard..... *1932*
Reiche, Parry: Geology of the Manzanita and North Manzano Mountains, New Mexico..... 1183
REINEMUND, J. A. (With C. C. ALBRITTON, JR. *et al.*): Structural features associated with lead and zinc ores of the Goodsprings district, Nevada..... *1869*
Relation of Seine series to granite at East Shoal Lake, Ontario. By E. L. Bruce and J. S. Ross..... *1875*
Relation of structure to petrology in the northern Bighorn Mountains, Wyoming. By F. W. Osterwald..... *1965*
Report of field investigation of Coachella Valley earthquake on December 4, 1948. By S. E. Warner..... *1958*
Review of coal research. By R. M. Kosanke..... *1901*
Rheomorphic breccias. By G. E. Goodspeed..... *1891*
Rhinoceros mold in basalt. By W. M. Chappell, J. W. Durham and D. E. Savage..... *1949*
RHOADES, E. D. (With W. H. IRWIN, *et al.*): Development and use of multiple packers by the Bureau of Reclamation for ground-water observation in engineering geology..... *1898*
RHOADES, ROGER: Geological and related activities in the Bureau of Reclamation, July 1948–July 1949..... *1916*
RICH, J. L.: Critical environments of deposition—shelf, slope, and bottom—and criteria for their recognition.. *1916*
RICHARDS, ARTHUR (With C. C. ALBRITTON, *et al.*): Structural features associated with lead and zinc ores of the Goodsprings district, Nevada..... *1869*
RICHTER, C. F.: Desert Hot Springs earthquake of December 4, 1948..... *1956*
Ripple marks of the Triassic Moenkopi formation. By E. D. McKee..... *1941*
ROBERTS, E. B.: Seismological activities of the U. S. Coast and Geodetic Survey during 1948..... *1957*
ROBERTS, R. J.: Structure and stratigraphy of the Antler Peak quadrangle, north-central Nevada..... *1917*
ROBERTS, W. A. (With FAUL, A.): New fossil footprints from Colorado..... *1886*
ROBERTSON, FLORENCE (With J. A. VOLK): Electronic seismograph..... *1956*
Rockies, Valley widening processes in the Colorado. By B. A. Tator..... 1771
ROEDDER, EDWIN: Preliminary report on the system leucite–SiO_2–FeO..... *1917*
ROGERS, A. F.: Chemical formula of kempite..... *1944*
—: Dolomite crystals of teruel habit from Lake Arthur, Chavez County, New Mexico..... *1943*
Role of yttrium and other minor elements in the garnet group. By H. W. Jaffe..... *1899*
ROMNEY, CARL (With PERRY BYERLY): Nevada earthquakes..... *1953*
ROSE, W. B.: Geological features of North Dakota lignites *1917*
Ross, J. S. (With E. L. BRUCE): Relation of the Seine series to granite at East Shoal Lake, Ontario..... *1875*
Ross, M. H.: Source and correlations of the Deepkill conglomerates..... *1973*
ROTH, ROBERT: Paleogeology of the Panhandle of Texas. . 1671
ROTHROCK, H E.: Study of the Pennsylvania anthracite fields..... *1973*
ROTHWELL, W. T. JR.: Preliminary report on Ostracoda in bottom samples and cores of northwestern Gulf of Mexico..... *1918*
RUSSELL, R. D. (With A. CARSOLA and R. S. DIETZ): Submarine geology of two northeast Pacific sea mounts. *1878*
RUTTEN, L. M. R.: Frequency and periodicity of orogenetic movements..... 1755

SAPLIS, R. A., AND FLINT, D. E.: Ramparts on the elevated atoll of Kita Daito Jima..... *1974*
SAVAGE, D. E. (With W. M. CHAPPELL and J. W. DURHAM): Rhinoceros mold in basalt..... *1949*
SCHAFER, J. P.: Pleistocene geology of the upper Teton River, central Montana..... *1974*
SCHAFFER, P. R. (With M. M. LEIGHTON): Newly discovered extension of the Labradorean ice sheet into eastern Iowa during the Tazewell substage of the Wisconsin stage..... *1904*
Scheme of the chemistry of the ore veins based on qualitative spectrographic analysis. By Jan Kutina..... *1502*
SCHIECK, E. E. (With H. E. SUMMERFORD and T. C HIESTAND): Lithofacies problems, Newcastle sandstone, Mush Creek and Skull Creek area, Weston County, Wyoming..... *1965*
SCHIELTZ, N. C. (With R. C. MIELENZ, *et al.*): Materials for pozzolan..... *1964*
Schist, at Philadelphia, Wissahickon. By Judith Weiss.... 1689
SCHMITT, HARRISON: Origin of the epithermal mineral deposits..... *1918*
SCOTT, W. F. (With H. E. WHEELER and T. L. THOMPSON): Permian-Mesozoic stratigraphy in northeastern Nevada..... *1928*
Sea-floor investigations in the north Pacific and Bering Sea. By R. S. Dietz and E. C. Bullington..... *1882*
Sedimentary basins of Arizona and adjoining areas. By E. D. McKee..... *1908*
— cycles in the Dunkard and Monongahela series of Ohio. By A. T. Cross..... *1881*
Sedimentation, Glacial erosion and. By C. D. Holmes... 1429
Seismic evidence for the fault origin of oceanic deeps. By Hugo Benioff..... 1837
— refraction measurements in the Atlantic Ocean basin. By Maurice Ewing, J. L. Worzel, J. B. Hersey, Frank Press, and G. R. Hamilton..... 1303
— studies in ocean basins. By Maurice Ewing..... *1885*
Seismological activities of the U. S. Coast and Geodetic Survey during 1948. By E. B. Roberts..... *1957*
Sequence of Cambrian trilobite faunas in southeastern Arizona. By Alexander Stoyanow..... *1922*

Setting of Arizona in Cordilleran structure. By B. S. Butler ... *1877*

SHAININ, V. E.: Age determinations of pegmatites of Topsham, Maine ... 1727

SHAND, S. J.: History of a feldspar crystal ... 1213

SHARP, R. P.: Features of the Seward firn field, St. Elias Range, Canada ... *1918*

—: Glaciological studies on the Seward ice field, Canada, during 1948 ... *1944*

SHEPARD, F. P.: Significance of depth changes in submarine canyon heads ... *1945*

—: Submarine geology investigations at Scripps Institution of Oceanography ... *1919*

—: Terrestrial topography of submarine canyons revealed by diving ... 1597

Sierra Nevada, Quaternary geology of the June Lake district, California. By W. C. Putnam ... 1281

Significance of depth changes in submarine canyon heads. By F. P. Shepard ... *1945*

— — explosive evolution for diastrophic division of earth history. By Lloyd Henbest ... *1894*

— — gallium and germanium replacement in synthetic feldspars. By J. R. Goldsmith ... *1891*

Simple method of preparing crystal models. By A. J. Gude. *1961*

SIMPSON, G. G.: Periodicity in vertebrate evolution ... *1919*

Simpson group, west Texas and southeastern New Mexico. By J. H. Bartley ... *1872*

SLOSS, L. L. AND MORITZ, C. A.: Paleozoic stratigraphy of southwestern Montana ... *1920*

— (With C. A. MORITZ): Mesozoic stratigraphy of southwestern Montana ... *1910*

SMITH, J. FRED, JR. (With C. C. ALBRITTON, JR.): Marfa Basin, Hudspeth County, Texas ... *1869*

SMITH, H. T. U.: Dune forms in western Nebraska ... *1920*

—: Physical effects of Pleistocene climatic changes in nonglaciated areas ... 1485

— (With JAMES THORP): Map of eolian deposits in North America ... *1923*

SMITH, J. F., JR., and C. C. ALBRITTON, JR.: Conglomerates of western Trans-Pecos Texas and their relation to a tectonic boundary ... *1921*

SOCOLOW, A. A.: Geology of the Irwin district of Colorado. *1921*

Some geologic factors in subterranean construction. By G. A. Kiersch ... *1940*

Sorting of sediments in the light of fluid mechanics. By D. L. Inman ... *1940*

Source and correlations of the Deepkill conglomerates. By M. H. Ross ... *1973*

Spectrochemical analysis of rocks. By L. W. Strock and Ladislav Dejnozka ... *1975*

Spontaneous growth of radially constructed crystal aggregates from supercooled melts. By K. H. Engel ... *1968*

STANLEY, G. M.: Elevations of some Lake Lahontan shore lines ... *1945*

STAPLES, L. W.: Cubic pseudomorphs of quartz after halite in petrified wood ... *1945*

Statistical treatment of facies change. By P. A. Chenoweth *1967*

STECHSCHULTE, V. C., S. J.: Method of obtaining a travel-time curve within a stripped earth ... *1957*

Stille's theory of diastrophism, criticism of. By L. M. R. Rutten ... 1755

STIRTON, R. A.: New ceboid monkeys from the La Venta Late Miocene of Colombia, South America ... *1921*

— AND GEALEY, W. K.: Reconnaissance geology and vertebrate paleontology of El Salvador, Central America ... 1731

STOBBE, H LEN: Dacites from Laughlin Peak, Colfax County, New Mexico ... *1922*

STOYANOW, ALEXANDER: Occurrence of Texan Permian ammonoids in Arizona ... *1946*

—: Sequence of Cambrian trilobite faunas in southeastern Arizona ... 1922

STRAHLER, A. N.: Frequency-distribution analysis of slopes ... 1971

Stratigraphic and micropaleontologic analysis of the Maqfi section Farafra Oasis, western Desert of Egypt. By L. W. LeRoy ... 1992

Stratigraphy

Geology of the Monadnock region of New Hampshire. By Katharine Fowler-Billings ... 1269

—, Problems of Pleistocene. By L. L. Ray ... 1469

— and faunal relationships of the Upper Cambrian in the central Appalachians. By J. L. Wilson ... 1979

— — petrology of the Buck Hill Quadrangle, Texas. By S. S. Goldich and M. A. Elms ... 1133

— — structure of the Capitola quadrangle, California. By C. N. Beard ... 1938

— of the Arbuckle limestone, Arbuckle Mountains, Oklahoma. By W. E. Ham ... 1893

— — Centennial region, Beaverhead County, Montana. By F. S. Honkala ... 1877

— — Paleozoic and Mesozoic rocks in the Piedra River Canyon, Archuleta County, Colorado. By G. H. Wood 1931

Stream terracing. By H. T. U. Smith ... 1469

STRINGHAM, BRONSON AND TAYLOR, A. O.: Nontronite at Bingham, Utah ... 1923

STROCK, L. W., AND DEJNOZKA, LADISLAV: Spectrochemical analysis of rocks ... 1975

Structural analysis of the west border of the Durham Triassic basin. By J. W. Harrington ... 1893

— features associated with lead and zinc ores of the Goodsprings district, Nevada. By C. C. Albritton, Jr., Arthur Richards, J. A. Reinemund, and D. A. Phoenix ... 1889

— history of the Hudson Valley. By R. H. Flower ... 1989

— reconnaissance of the Red Rock quadrangle, Arizona. By J. H. Feth ... 1887

Structure

Fault origin of oceanic deeps. By Hugo Benioff ... 1837

Geology of the Monadnock region of New Hampshire. By Katharine Fowler-Billings ... 1269

—, metamorphism and granitization in part of Okanogan County, north-central Washington. By Peter Misch ... 1942

— and metamorphism of the Keene-Brattleboro area, New Hampshire-Vermont. By George E. Moore, Jr. 1463

— — stratigraphy of the Antler Peak quadrangle, north-central Nevada. By R. J. Roberts ... 1917

— in Arizona. By E. D. Wilson ... 1939

— — Arizona-Nevada boundary area. By C. R. Longwell ... 1905

— of Candelaria district, Mineral County, Nevada. By B. M. Page ... 1943

— — Manzanita and North Manzano Mountains, New Mexico. By Parry Reiche ... 1283

— — North Atlantic, Submarine. By Ivan Tolstoy and Maurice Ewing ... 1937

— — Precambrian, Denver Mtn. Parks quadrangle, Colorado. By M. F. Boos ... 1879

Studies of ocean-bottom structure off Southern California with explosive waves. By R. W. Raitt ... 1965

Study of the Pennsylvania anthracite fields. By H. E. Rothrock ... 1973

Submarine canyons, currents in. By F. P. Shepard ... 1597

— — origin of. By F. P. Shepard ... 1597

— — photography in La Jolla. By F. P. Shepard ... 1599

— — relation to land canyons. By F. P. Shepard ... 1597

— — revealed by diving, Terrestrial topography of. By F. P. Shepard ... 1599

— geology

Fault origin of oceanic deeps. By Hugo Benioff ... 1837

— —: Swedish deep sea expedition, 1947–1948. By Hans Pettersson ... 1924

Submarine geology and Pleistocene Research. By F. B Phleger 1457
— — in the North Atlantic. By Ivan Tolstoy *1924*
— — investigations at Scripps Institution of Oceanography. By F. P. Shepard *1919*
— — of two northeast Pacific sea mounts. By A. Carsola, R. S. Dietz and R. D. Russell *1878*
— topography of Atlantic Ocean. By Ivan Tolstoy and Maurice Ewing 1527
Subsurface Woodford black shale of west Texas and southeast New Mexico. By S. P. Ellison, Jr. *1885*
SUMMERFORD, H. E., SCHIECK, E. E. AND HIESTAND, T. C.: Lithofacies problems, Newcastle sandstone, Mush Creek and Skull Creek area, Weston County, Wyoming *1965*
Surface area of deep-sea sediments. By J. L. Kulp and D. R. Carr *1902*
Survey of the mineralogy of uranium. By Clifford Frondel. *1889*
Synthesis of piezoelectric minerals for frequency control. By H. H. Waesche *1975*
Synthetic quartzite. By H. W. Fairbairn *1886*
System $NaAlSi_3O_8$–$KAlSi_3O_8$–H_2O. By N. L. Bowen and O. F. Tuttle *1874*

"T" phase of shallow-focus submarine earthquakes. By Ivan Tolstoy, Maurice, Ewing, and Frank Press *1957*
TATOR, B. A.: Valley widening processes in the Colorado Rockies 1771
TAYLOR, A. O. (With BRONSON STRINGHAM): Nontronite at Bingham, Utah *1923*
Terracing, Stream. By H. T. U. Smith 1485
Terrain displacements of the Philippine Islands. By P. B. King and E. M. McKee 1829
Terrestrial topography of submarine canyons revealed by diving. By F. P. Shepard 1597
TEXAS, Paleogeology of the Panhandle of. By Robert Roth 1671
—, Stratigraphy and petrology of Buck Hill quadrangle. By S. S. Goldich and M. A. Elms 1133
Thermal metamorphism in the central Kuskokwim region, southwestern Alaska. By R. E. Wallace, W. M. Cady, E. J. Webber, and J. M. Hoare *1946*
THOMPSON, T. L. (With H. E. WHEELER and W. F. SCOTT): Permian-Mesozoic stratigraphy in northeastern Nevada *1928*
THORP, JAMES: Interrelations of Pleistocene geology and soil science 1517
THORP, JAMES AND SMITH, H. T. U.: Map of eolian deposits in North America *1923*
Thrust faulting in the Empire Mountains, southeastern Arizona. By F. W. Galbraith *1889*
Tidal-flat environment. By D. J. Doeglas, A. Koning, and J. H. Germeraad *1882*
Titanomagnetite rocks of the western San Gabriel Mountains, California. By G. B. Oakeshott *1942*
TITTLE, C. W., GOODMAN, CLARK, AND FAUL, HENRY: Nuclear radiations in well logging *1923*
— (With HENRY FAUL and CLARK GOODMAN): Neutron logging of drill holes *1886*
TOLSTOY, IVAN: Submarine topography in the North Atlantic *1924*
— AND EWING, MAURICE: North Atlantic hydrography and the Mid-Atlantic Ridge 1527
— EWING, MAURICE, AND PRESS, FRANK: "T" phase of shallow-focus submarine earthquakes *1657*
— (With MAURICE EWING and FRANK PRESS): Proposed tsunami warning system *1954*
— (With FRANK PRESS and MAURICE EWING): Airy phase of shallow-focus submarine earthquakes *1956*
TOMLINSON, W. H.: Assimilation (?) of micaceous schist by diabase *1924*
Topography of Atlantic Ocean, Submarine. By Ivan Tolstoy and Maurice Ewing 1527
TRACEY, J. I. (With MACKENZIE GORDON and M. W. ELLIS): Field relations of Arkansas bauxite deposits .. *1891*
TREASHER, R. C.: Engineering geology of the Isabella project, California *1946*
—: Kern Canyon fault, Kern County, California *1957*
Trends in glaciology in Europe. By Henri Bader 1309
Triassic to Tertiary stratigraphy near Cerro de Pasco, Peru. By W. F. Jenks *1900*
TUNNELL, G., AND ADAMS, C. E.: Crystal structure of bornite from Illogan, Cornwall *1925*
TURNER, D. S.: Notes on permafrost in construction engineering *1966*
"Turtlebacks" of central Black Mountains, Death Valley, California. By H. D. Curry *1882*
TUTTLE, O. F.: Two-pressure vessels for silicate-water studies 1727
— AND BOWEN, N. L.: High-temperature albite *1925*
— (With N. L. BOWEN): System $NaAlSi_3O_8$–$KAlSi_3O_8$–H_2O *1874*
Two-pressure vessels for silicate-water studies. By O. F. Tuttle 1727
TYLER, S. A.: Development of Lake Superior soft iron ore from metamorphosed iron formations 1101

Upper Devonian ophiurans in central New York. By R. B. Johnson *1971*
UPSON, J. E.: Former marine shore lines of the Gaviota quadrangle, Santa Barbara County, California *1925*
Use of a variable-field electromagnetic mineral separator in sedimentary petrography. By J. D. Frautschy *1888*

Valley widening processes in the Colorado Rockies. By B. A. Tator 1771
Venezuela, Geological reconnaissance of the Island of Margarita. By H. H. Hess and J. C. Maxwell 1857
Verdi, Nevada, earthquake of December 29, 1948. By V. P. Gianella *1938*
Vermont, Structure and metamorphism of the Keene Brattleboro area, New Hampshire. By G. E. Moore, Jr. 1613
Vertebrate Paleontology in North America, Pleistocene. By C. W. Hibbard 1417
Vertebrate paleontology of El Salvador, Central America, Reconnaissance geology and. By R. A. Stirton and W. K. Gealey 1731
VITALIANO, C. J. (With BRIAN MASON): Preliminary account of the naturally occurring antimony oxides ... *1907*
Volatile transfer
Hawaiian Islands. By G. A. Macdonald 1541
Volcanic rocks in the Candelaria district, west-central Nevada. By J. D. Barksdale *1936*
VOLK, J. A. AND ROBERTSON, FLORENCE: Electronic seismograph *1958*

WAESCHE H. H.: Synthesis of piezoelectric minerals for frequency control *1975*
WAHLSTROM, E. E.: Melonite from Boulder County, Colorado *1926*
Wall-rock replacement by oxidized copper minerals. By R. M. Dreyer, A. L. Howland and R. M. Garrels *1884*
WALLACE, R. E., *et al.*: Thermal metamorphism in the central Kuskokwim region, southwestern Alaska *1946*
WARNER, S. E.: Report of field investigation of Coachella Valley earthquake on December 4, 1948 ..... *1958*
WARREN, C. R.: Probable Illinoian age of part of the Missouri River *1926*
WARREN, H. V. AND DELAVAULT, R. E.: Gold and silver content of some trees and horsetails in British Columbia *1947*

WARTHIN, A. S.: Wax and wane of species in Paleozoic Ostracoda ... *1926*
WASHKEN, EDWARD, AND BUERGER, M. J.: Effect of potassium on the nepheline-carnegieite transformation ... *1927*
Wax and wane of species in Paleozoic Ostracoda. By A. S. Warthin ... *1926*
WEBBER, E. J. (With R. E. WALLACE, *et al.*): Thermal metamorphism in the central Kuskokwim region, southwestern Alaska ... *1946*
WEIMER, R. J. (With E. L. HEISEY and D. E. LAWSON): Geology of Whiskey Gap-Muddy Gap and Ferris Mountains region, Wyoming ... *1961*
WEIR, GORDON (With W. P. POPENOE): Cretaceous, Baja California ... *1943*
WEISS, JUDITH: Wissahickon schist at Philadelphia ... *1689*
WELLS, F. G.: Ensimatic and ensialic geosynclines ... *1927*
West Texas Geological Society, Stratigraphic Committee: East-west cross section through the southern Permian basin of west Texas ... *1928*
WHEELER, H. E., SCOTT, W. F., AND THOMPSON, T. L.: Permian-Mesozoic stratigraphy in northeastern Nevada ... *1928*
WHITE, S. E.: Preliminary report on geology of Popocatepetl, Mexico ... *1976*
WILLARD, BRADFORD: Cambrian stratigraphic nomenclature in eastern Pennsylvania ... *1976*
WILLIAMS, HOWEL: Geology of Shasta Valley and the adjacent Cascades, northeastern California ... *1947*
WILLIAMS, J. S.: Diverse concepts of the Amsden formation ... *1928*
WILLMAN, H. B. (With M. M. LEIGHTON): Loess formations of Mississippi Valley ... *1904*
WILSON, E. D.: Structure in Arizona ... [illegible]
WILSON, J. A.: Indications of a large coelacanth fish in the Permian Vale formation of Texas ... [illegible]
WILSON, J. L.: Stratigraphy and faunal relationships of the Upper Cambrian in the central Appalachians ... [illegible]
WILSON, R. W.: Preliminary report on a Torrejonian faunule from near Angels Peak, San Juan Basin, New Mexico ... [illegible]
Wisconsin glacial stadia in New Jersey. By Paul MacClintock and L. C. Peltier ... [illegible]
Wissahickon schist at Philadelphia, Penna. By Judith Weiss ... [illegible]
WOLFSON, ALBERT: Biogeography and the nature of continents ... [illegible]
WOOD, G. H.: Stratigraphy of Paleozoic and Mesozoic rocks in the Piedra River Canyon, Archuleta County, Colorado ... [illegible]
WOOLLARD, G. P.: Regional gravity study of the Appalachian Mountain system ... [illegible]
WORZEL, J. L. (With MAURICE EWING, *et al.*): Seismic refraction measurements in the Atlantic Ocean Basin ... [illegible]
WRIGHT, L. A.: Crystal Spring formation, southern Death Valley Area, California ... [illegible]
—: Geology of the Silver Lake talc area, San Bernardino County, California ... [illegible]

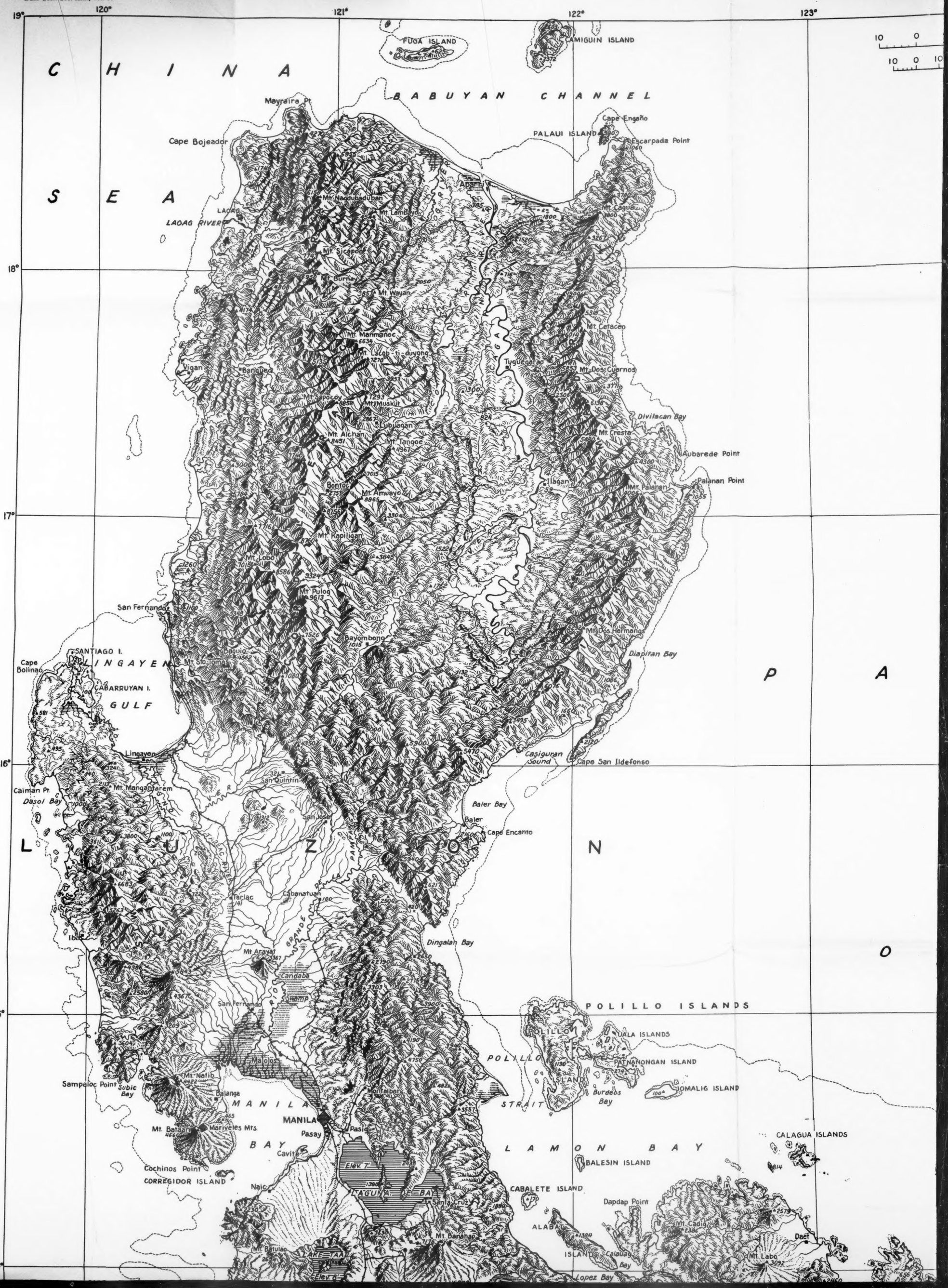
YODER, H. S., JR.: Jadeite problem ... [illegible]

Zonation and correlation of the Pierre shale of Colorado. By M. O. Griffitts ... [illegible]

fish in the 179
..... 183
nships of
ians..... 189
rrejonian
asin, New
..... 193
MacClin-
..... 197
ma. By
..... 199
e of con-
..... 201
Mes zoic
a County,
..... 203
of the
..... 205
smic re-
asin..... 139
n Death
..... 209
nardino
..... 209

..... 213

lorado.
..... 161


19°
18°
17°
16°
15°
14°
120°
121°
122°
123°
C H I N A
S E A
P A C I F I C O C E A N
BABUYAN CHANNEL
FUGA ISLAND
CAMIGUIN ISLAND
Mayraira Pt.
Cape Bojeador
Cape Engaño
PALAUI ISLAND
Escarpada Point
Aparri
LAOAG
LAOAG RIVER
Mt. Naddubadduban
Mt. Lambayo
Mt. Sicapoo
Mt. Burnay
Mt. Wayan
Mt. Cagua
Mt. Cetaceo
Mt. Manmanoc
Mt. Lacab-ti-duyong
Tuguegarao
Mt. Dos Cuernos
Vigan
Banuyed
Mt. Sapocoy
Mt. Muskut
Lubuagan
Divilacan Bay
Mt. Aichan
Mt. Tangoe
Mt. Creste
Aubarede Point
Ilagan
Mt. Palanan
Palanan Point
Bontoc
Mt. Amuayo
Mt. Kapiligan
Mt. Lobo
Mt. Pulog
San Fernando
Bayombong
Mt. Dos Hermanos
Diapitan Bay
SANTIAGO I.
LINGAYEN
Cape Bolinao
CABARRUYAN I.
GULF
Baguio
Mt. Sto. Tomas
Lingayen
Caiman Pt.
Dasol Bay
Mt. Mangantarem
San Quintin
San Jose
Casiguran Sound
Cape San Ildefonso
Baler Bay
Baler
Cape Encanto
L U Z O N
Tarlac
Cabanatuan
Ibe
Mt. Arayat
Candaba swamp
Dingalan Bay
POLILLO ISLANDS
POLILLO
POLILLO ISLAND
UALA ISLANDS
PATNANONGAN ISLAND
JOMALIG ISLAND
Burdeos Bay
STRAIT
Sampaloc Point
Subic Bay
Mt. Natib
Balanga
Mariveles Mts.
Mt. Bataan
MANILA BAY
MANILA
Pasay
Pasig
Cavite
Cochinos Point
CORREGIDOR ISLAND
Naic
LAGUNA DE BAY
Santa Cruz
Mt. Banahao
LAMON BAY
CALAGUA ISLANDS
BALESIN ISLAND
CABALETE ISLAND
Dapdap Point
ALABAT ISLAND
Mt. Cadig
Daet
Calauag Bay
Mt. Labo
Lopez Bay
LAKE TAAL
Mt. Batulao
Elev. 7'
Elev. 6'

122° 123° 124° 125° 126°

19° 18° 17° 16° 15° 14°

10 0 10 20 30 40 50 Statute Miles

10 0 10 20 30 40 50 60 70 Kilometers

EXPLANATION

Railroads (all narrow gauge, 3' 6")

Lakes

Swamps

Coral reefs (some sand banks included)

Sand banks and submerged mud flats

100 fathom submarine contour

Terrain diagram drawn on map base, A.M.S. 5301, Sheets NC 51, ND 51, and NE 51, 1:1,000,000. Details sketched from U.S. Coast and Geodetic Survey Charts, 1:100,000 to 1:200,000; Philippine Coast and Geodetic Survey maps 3-17, 1:200,000; Military Survey of Luzon, A. M. S. S711, 1:63,360; and from geologic and topographic maps of National Development Company, various scales. Altitudes in feet above sea level. Summits of hills and ridges are offset about 1/10 inch northward for each 3000 feet of altitude above sea level to give the impression of relief. Horizontal distances can be scaled only between points of equal altitude.

CAMIGUIN ISLAND

372

C H A N N E L

Cape Engaño

PALAUI ISLAND

Escarpada Point

1060

3780

Mt. Cagua

3000

3267

1800

5348

Mt. Cetaceo

5253

Mt. Dos Cuernos

3771

4304

6136

Divilacan Bay

Mt. Cresta

5280

Aubarede Point

4300

Ilagan

Palanan Point

Mt. Palanan

2006

1055

5157

Mt. Dos Hermanos

Diapitan Bay

1086

1650

2120

Cape San Ildefonso

P A C I F I C

N O C E A N

POLILLO ISLANDS

UALA ISLANDS

PATNANONGAN ISLAND

2149

Burdeos Bay

100+

JOMALIG ISLAND

CALAGUA ISLANDS

814

O N B A Y

BALESIN ISLAND

Dapdap Point

2579

Mt. Cadig

2340

1384

Daet

Calauag Bay

Mt. Labo

3092

Lopez Bay

1656

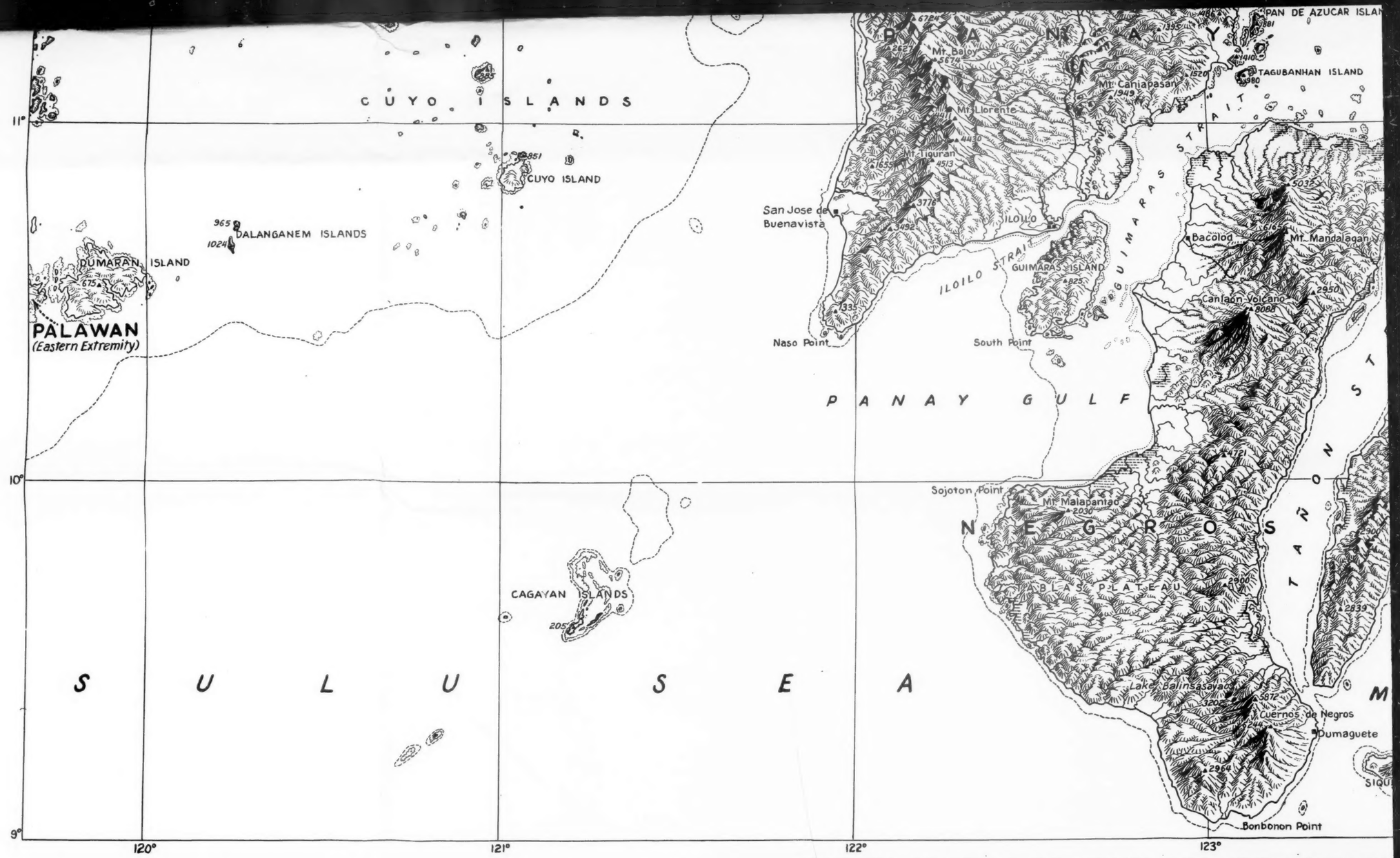
QUINALASAG ISLAND

Yog Point

1081

15°
14°
13°
12°
11°
POLILLO ISLANDS
POLILLO
UALA ISLANDS
PATNANONGAN ISLAND
POLILLO ISLAND
Burdeos Bay
JOMALIG ISLAND
STRAIT
CALAGUA ISLANDS
L A M O N B A Y
BALESIN ISLAND
CABALETE ISLAND
Dapdap Point
ALABAT ISLAND
Calauag Bay
Mt. Cadig
Mt. Labo
Daet
Lopez Bay
SAN MIGUEL BAY
Lucena
Naga
R A G A Y
G U L F
Boac
Mt. San Antonio
MARINDUQUE ISLAND
Boridoc Point
Dumali Point
DOS HERMANAS ISLANDS
BURIAS ISLAND
BANTON ISLAND
SIMARA ISLAND
S I B U Y A N
Romblon
ROMBLON ISLAND
Mt. Guitinguitin
SIBUYAN ISLAND
Bugui Point
TABLAS ISLAND
ROMBLON PASS
Pagbulungan Point
M A S E A
CARABAO ISLAND
Pitol Point
Pulandut
JINTOTOLO
JINTOTOLO CHANNEL
Pucio Point
Pandan Bay
Bulacaue Point
Pilar Bay
PAN DE
TAGUBANH
Mt. Caniapasan
Mt. Llorente
Mt. Naviotud
Mt. Baloy
Mt. Madiac
Mt. Agudo
P A N A Y
STRAIT
MANILA BAY
MANILA
Pasay
Pasig
Montalban
Marivales Mts.
Mt. Balagan
Cavite
Cochinos Point
CORREGIDOR ISLAND
Sampaloc Point
Subic Bay
Balanga
Mt. Natib
San Fernando
Candaba Swamp
Malolos
Naic
Elev. 7
LAGUNA DE BAY
Santa Cruz
Mt. Banahao
Mt. Batulao
AKE TAAL
Elev. 6
CABRA ISLAND
AMBIL ISLAND
LUBANG ISLAND
GOLA ISLAND
LUBANG ISLANDS
Cape Santiago
Balayan Bay
Balangas
TAYABAS BAY
Bantigui Point
MARICABAN ISLAND
VERDE ISLAND PASSAGE
Malabrigo Point
VERDE ISLAND
Mt. Calavite
Cape Calavite
Paluan Bay
Calapan
Mt. Halcon
M I N D O R O
Lake Naujan
MINDORO STRAIT
Mt. Baco
Dongon Point
APO ISLAND
Pandan Point
ILIN ISLAND
SEMIRARA ISLAND
SEMIRARA ISLANDS
CALUYA ISLAND
SIBAY ISLAND
ABLAS STRAIT
Coconongon Point
BUSUANGA ISLAND
CALAMIAN GROUP
Coron Bay
CORON ISLAND
CULION ISLAND
Linapacan Strait
LINAPACAN ISLAND
ILOC ISLAND
CABULAUAN ISLANDS
QUINILUBAN GROUP
CUYO ISLANDS

POLILLO ISLANDS
POLILLO
UALA ISLANDS
PATNANONGAN ISLAND
ISLAND
Burdeos Bay
JOMALIG ISLAND
M O N B A Y
CALAGUA ISLANDS
BALESIN ISLAND
ETE ISLAND
Dapdap Point
Mt. Cadig 2386
Daet
Mt. Labo 3092
ISLAND
Calaguay Bay
Lopez Bay
QUINALASAG ISLAND
SAN MIGUEL BAY
Mt. Isarog 6182
Yog Point
Maqueda Channel
CATANDUANES ISLAND
Nagumbuaya Point
Virac Point
RAGAY
Naga
COL
RIVER
LAGONOY
GULF
Mt. San Antonio 2459
Mt. Malinao 5079
Lake Bato
Mayon Volcano 7943
BATAN ISLAND
RAPURAPU ISLAND
ALBAY GULF
Bondoc Point
Legaspi
Bingay Point
OS HERMANAS ISLANDS
BURIAS ISLAND
Sorsogon
Sorsogon Bay
BANTON ISLAND
SIMARA ISLAND
Bulusan Volcano 5115
S I B U Y A N
Aguja Point
San Bernardino Strait
BALICUATRO ISLANDS
BATAG ISLAND
LAOANG ISLAND
Cape Espiritu Santo
Bugui Point
Romblon
ROMBLON ISLAND
ROMBLON PASS
Mt. Guiting-guitin 6750
SIBUYAN ISLAND
TICAO ISLAND
DALUPIRIT ISLAND
CAPUL ISLAND
NARANJO ISLANDS
Masbate
AUBIG RIVER
Gomay Bay
ORAS RIVER
Mt. Caporoan 2789
Mt. Cinyapu 2620
Bunga Point
Oras Bay
Pagbulungan Point
M A S B A T E
TAGAPULA ISLAND
S A M A R
S E A
Asid Gulf
Potol Point
Dumurug Point
ALMAGRO ISLAND
SANTO NINO ISLAND
MARIPIPI ISLAND
Pulanduta Point
JINTOTOLO ISLAND
JINTOTOLO CHANNEL
Catbalogan
Mt. Yacgem 2198
Paninihian Point
Caduruan Point
BILIRAN ISLAND
DARAM ISLAND
Bulacaue Point
GIGANTE ISLANDS
Pilar Bay
V I S A Y A N
CALAGNAAN ISLAND
Mt. Agudo 2736
Mt. Madiac 4390
Mt. Naiatud 6724
GUINTACAN ISLAND
S E A
Carigara Bay
Tugnug Point
Matarinao Bay
PAN DE AZUCAR ISLAND
Balalaqui Point
BANTAYAN ISLAND
P A N A Y
Mt. Baloy 5674
TAGUBANHAN ISLAND
Tacloban
San Pedro Bay
Mt. Cahiapasan 1949
Mt. Llorente
Nailon Point
L E Y T E
Mt. Majunag
CALICOAN ISLAND
STRAIT
Sagay Point
Ormoc Bay
L E Y T E G U L F
15°
14°
13°
12°
11°



TERRAIN DIAGRAM OF LUZON AND THE VISAYAN

By Philip B. King

TERRAIN DIAGRAM OF LUZON AND THE VISAYAN ISLANDS

By Philip B. King

PREPARED BY U. S. GEOLOGICAL SURVEY
FOR
CHIEF OF ENGINEERS, U. S. ARMY

TECHNOLOGY

122° 123° 124° 125° 126°

10 9 8 7 6

SULU SEA

MINDANAO SEA

CEBU ISLAND

NEGROS ISLAND

BOHOL ISLAND

SIQUIJOR ISLAND

DINAGAT I.

SIARGAO

Bilaa Point

SURIGAO

BUCAS GRANDE

Lake Mainit

Lanuza Bay

Mt. Hilong-hilong 602

CAMIGUIN ISLAND

Mt. Mambajao

Diuata Point

BUTUAN BAY

Bagacay Point

Gingoog Bay

BUTUAN

Mt. Malayapay 2360

Mt. Balatocan 4200

Tagolo Point

Sulauan Point

MACAJALAR BAY

Mt. Amaloy 3105

CAGAYAN

OROQUIETA

Mt. Ampiro 5330

Mt. Dapiak 8620

Mt. Malindang 7956

ILIGAN BAY

Port Misamis

Sindangan Bay

Sindangan Point

MISAMIS

Katanglad Mts.

MALAYBALAY

DANSALAN

Gurain Mts.

Lake Lanao 2297

Mt. Iniaoan 5204

Kalatungan Mts.

Mt. Ampaoid

Mt. Tangkulang 5505

Mt. Ragang 9235

Mt. Piapayungan

BUTIG MTS.

Sugarloaf Mtn. 6030

Mt. Baga 1935

Mt. Silingar 2950

Dulunguin Point

Lupilec Pk. 2240

SIBUGUEY BAY

VITALI ISLAND

OLUTANGA ISLAND

Dumanquilas Bay

Baganian Peninsula

ILLANA BAY

BONGO ISLAND

Polloc Hbr.

COTABATO

Mt. Bulusan 1030

Libungan Marsh

Mt. Blik 4021

Mt. Binaca 3350

ZAMBOANGA

SACOL ISLAND

BASILAN STRAIT

MORO GULF

PILAS GROUP

BASILAN ISLAND

TAPIANTANA GROUP

SAMALES GROUP

Iguasan Marsh

Mt. Libidan 2933

Lake Buluan

Mount Apo 9690

DAVAO

SAMAL I.

TALIKUD I.

Paet Point

DAVAO GULF

Colapsin Pt.

Mt. Matutum

Mt. Latian 5288

Lake Sebu

Parker Volcano

Sarangani Bay

Terrain diagram drawn on map base, AMS5301, 1:1,000,000, sheets NC51, NC52, NB51, and NB52. Details added from Philippine Coast and Geodetic Survey Map 50, Mindanao, 1:600,000; from U.S. Coast and Geodetic Survey charts, 1:50,000 to 1:200,000; and from military, geological, and forest surveys. Data supplemental where possible from photographs, published descriptions, and oral accounts. Altitudes in feet above sea level.

TECHNOLOGY DEPT.
TECHNOLOGY

123° 124° 125° 126° 127°

CEBU ISLAND
BOHOL ISLAND
NEGROS ISLAND
SIQUIJOR ISLAND
CAMIGUIN ISLAND
Mt. Mambajao
DINAGAT I.
SIARGAO ISLAND
Bilaa Point
SURIGAO
BUCAS GRANDE ISLAND
Lake Mainit
Lanuza Bay
Cauit Point
Mt. Hilong-hilong
Diuata Point
BUTUAN BAY
Bagacay Point
Gingoog Bay
BUTUAN
Mt. Malayapay
Mt. Balatocan
Umanun Point
Tagolo Point
Sulauan Point
MACAJALAR BAY
Mt. Diuata
Mt. Amaloy
CAGAYAN
Lianga Bay
OROQUIETA
Mt. Ampiro
Mt. Dapiak
Mt. Malindang
ILIGAN BAY
Lemon Point
Sindangan Bay
Sindangan Point
Port Misamis
MISAMIS
Agus River
Sanco Point
Cateel Bay
Sugarloaf Mtn.
Gurain Mts.
Lake Lanao
DANSALAN
Mt. Iniaoan
Mt. Baga
Mt. Ragang
Mt. Piapayungan
BUKIDNON MTS.
Mt. Tangkulang
Mt. Agtuuganon
Bangai Point
Dumanquilas Bay
Baganian Peninsula
ILLANA BAY
Pollok Hbr.
COTABATO
Mt. Buluan
Mt. Kampalili
BONGO ISLAND
Libungan Marsh
Mt. Blil
Mt. Biriac
Liguasan Marsh
DAVAO
SAMAL I.
Mount Apo
Mt. Mayo
Tugubun Point
TALIKUD
Paet Point
Mayo Bay
Lamigan Point
Pujada Bay
Lake Buluan
Colapsin Pt.
Mt. Matutum
Mt. Lariam
Cape San Agustin
Lake Sebu
Parker Volcano
Sarangani

Terrain diagram drawn on map base, AMS5301, 1:1,000,000, sheets NC51, NC52, NB51, and NB52. Details added from Philippine Coast and Geodetic Survey Map 50, Mindanao, 1:600,000; from U.S. Coast and Geodetic Survey charts, 1:50,000 to 1:200,000; and from military, geological, and forest surveys. Data supplemental where possible from photographs, published descriptions, and oral accounts. Altitudes in feet above sea level.

Terrain diagram drawn on map base, AMS5301, 1:1,000,000, sheets NC51, NC52, NB51, and NB52. Details added from Philippine Coast and Geodetic Survey Map 50, Mindanao, 1:600,000; from U.S. Coast and Geodetic Survey charts, 1:50,000 to 1:200,000; and from military, geological, and forest surveys. Data supplemental where possible from photographs, published descriptions, and oral accounts. Altitudes in feet above sea level.

Towns (only more important shown)

Main roads

Marsh or swamp (Fresh water marshes inland; mangrove swamps along coast

Lakes

Sandy beach

Submerged mud flats

Coral reefs (Includes some sand banks

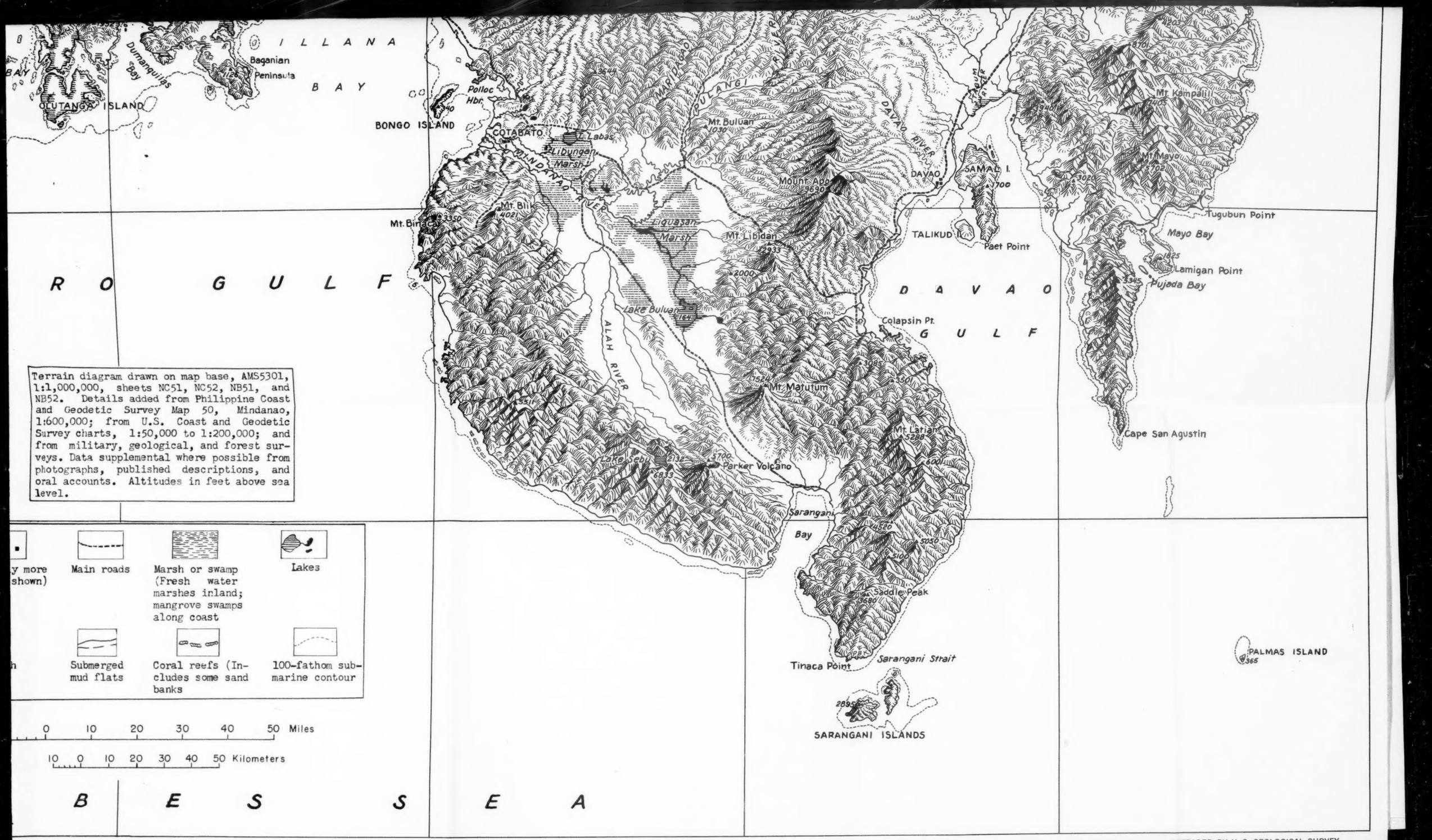
100-fathom submarine contour

10 0 10 20 30 40 50 Miles

10 0 10 20 30 40 50 Kilometers

TERRAIN DIAGRAM OF MINDANAO

By Philip B. King



Terrain diagram drawn on map base, AMS5301, 1:1,000,000, sheets NC51, NC52, NB51, and NB52. Details added from Philippine Coast and Geodetic Survey Map 50, Mindanao, 1:600,000; from U.S. Coast and Geodetic Survey charts, 1:50,000 to 1:200,000; and from military, geological, and forest surveys. Data supplemental where possible from photographs, published descriptions, and oral accounts. Altitudes in feet above sea level.

y more shown)

Main roads

Marsh or swamp (Fresh water marshes inland; mangrove swamps along coast

Lakes

Submerged mud flats

Coral reefs (Includes some sand banks

100-fathom submarine contour

0 10 20 30 40 50 Miles

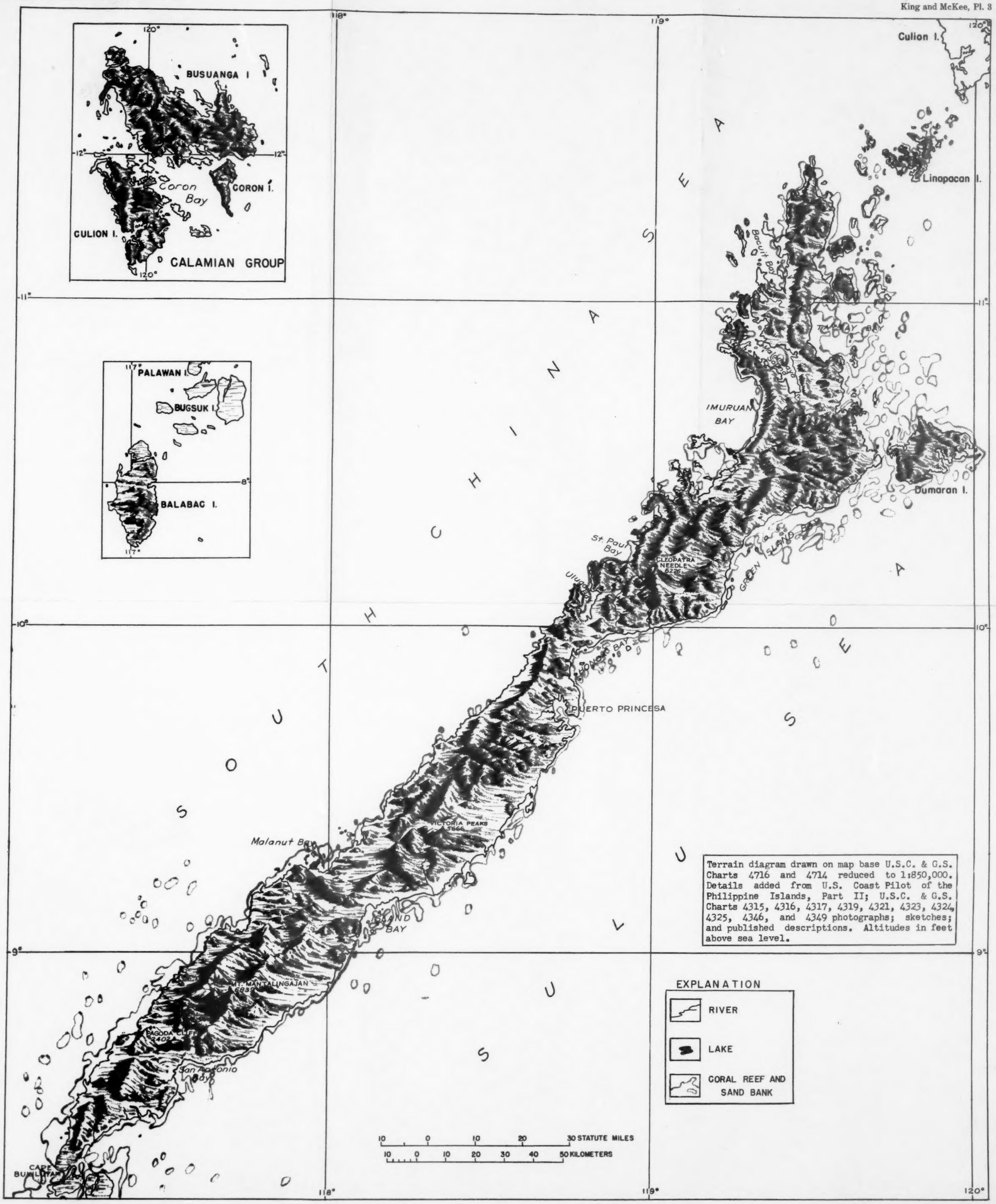
10 0 10 20 30 40 50 Kilometers

TERRAIN DIAGRAM OF MINDANAO

By Philip B. King

PREPARED BY U. S. GEOLOGICAL SURVEY
FOR
CHIEF OF ENGINEERS, U. S. ARMY

TECHNOLOGY DEPT.

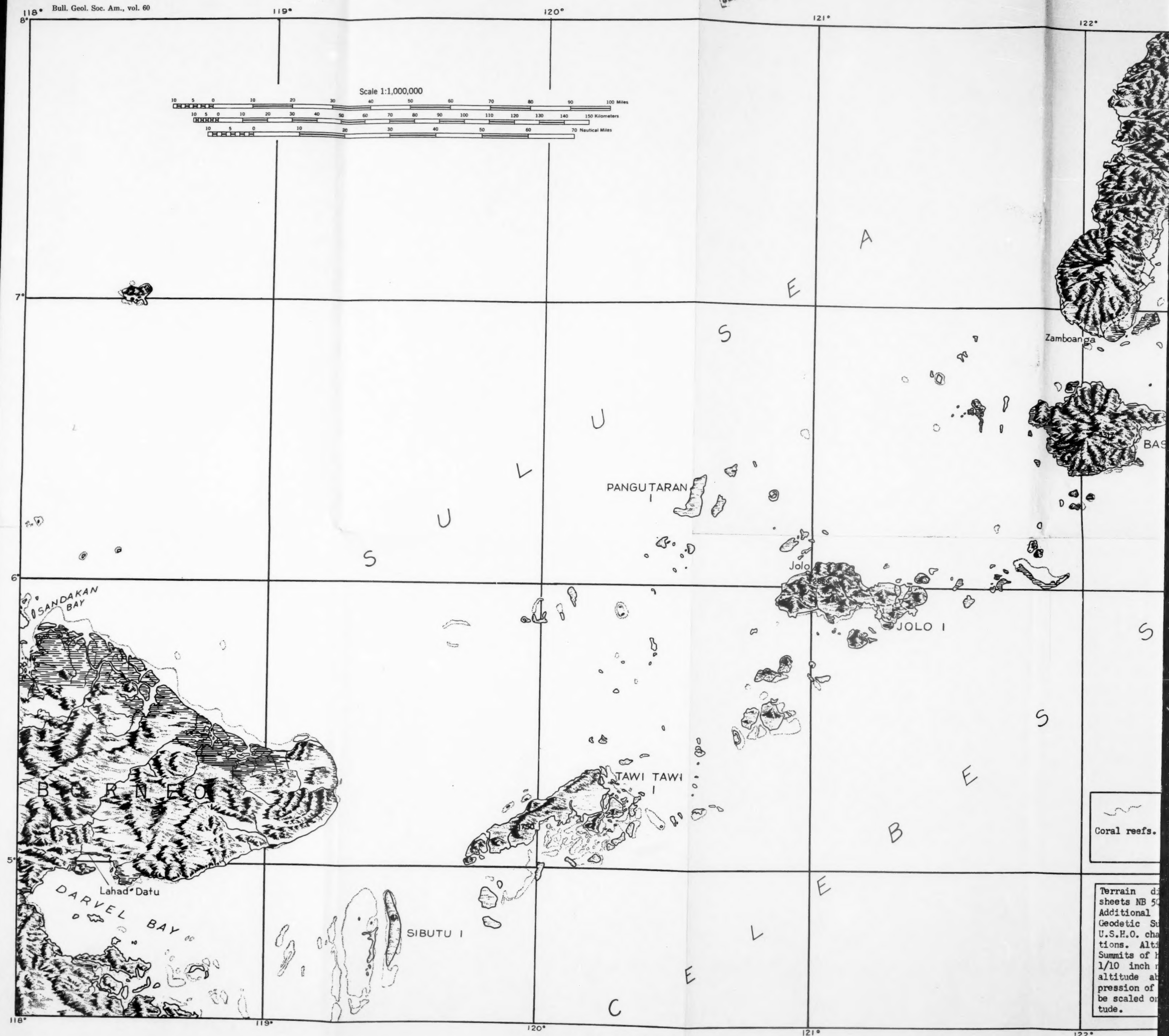


TERRAIN DIAGRAM OF PALAWAN

By Edith M. McKee

PREPARED BY U. S. GEOLOGICAL SURVEY
FOR
CHIEF OF ENGINEERS, U. S. ARMY

TECHNOLOGY DEPT.



TERRAIN DIAGRAM OF SULU ARCHIPELAGO

By Edith M. McKee

TECHNOLOGY DEPT.

119° 120° 121° 122° 123°

8°

7°

6°

5°

Scale 1:1,000,000

20 30 40 50 60 70 80 90 100 Miles

20 30 40 50 60 70 80 90 100 110 120 130 140 150 Kilometers

10 20 30 40 50 60 70 Nautical Miles

SIBUGUEY BAY

Zamboanga

BASILAN I

PANGUTARAN I

Jolo

JOLO I

TAWI TAWI I

SIBUTU I

SULU SEA

SULU SEA

Coral reefs. Swamps Roads (incompletely shown).

Terrain diagram on map base AMS 5301, sheets NB 50 and NB 51, scale of 1:1,000,000. Additional data from Philippine Coast and Geodetic Survey Map 50 (Mindanao 1:60,000), U.S.H.O. charts, views, and written descriptions. Altitudes in feet above sea level. Summits of hills and ridges are offset about 1/10 inch northward for each 3000 feet of altitude above sea level to give the impression of relief. Horizontal distances can be scaled only between points of equal altitude.

TERRAIN DIAGRAM OF SULU ARCHIPELAGO

By Edith M. McKee

PREPARED BY U. S. GEOLOGICAL SURVEY
FOR
CHIEF OF ENGINEERS, U. S. ARMY

TECHNOLOGY DEPT.

EXPLANATION

TERTIARY QUATERNARY

Sediments

Volcanics

Sediments

Volcanics

MESOZOIC (?)

Basement rocks
(Known areas of ultrabasic rocks in black)

Axis of anticline or anticlinorium

Axis of syncline or synclinorium

General strike and dip of beds

General course of Philippine fault zone
Other faults not shown

Volcanoes
Solid circles, active volcanoes or fresh cones; open circles, dissected cones

Submarine contours
Depths in fathoms; showing 100 fathom contour, and 500 fathom contours below 1000 fathoms

118° 120° 122° 124° 126°

18° 16° 14° 12° 10°

PACIFIC OCEAN

SOUTH CHINA SEA

LUZON

MINDORO

SIBUYAN SEA

MASBATE

SAMAR

VISAYAN SEA

PANAY

NEGROS

CEBU

BOHOL

MINDANAO SEA

MINDANAO TRENCH

PALAWAN

Other faults not shown

Volcanoes
Solid circles, active volcanoes or fresh cones; open circles, dissected cones

Submarine contours
Depths in fathoms; showing 100 fathom contour, and 500 fathom contours below 1000 fathoms

LUZON
MINDORO
SIBUYAN SEA
MASBATE
SAMAR
VISAYAN SEA
PANAY
NEGROS
BOHOL
MINDANAO SEA
MINDANAO
PHILIPPINE TRENCH
PALAWAN
SULU SEA
MORO GULF
SULU ARCHIPELAGO
BORNEO
CELEBES SEA

0 50 100 200 MILES

GEOLOGIC AND TECTONIC SKETCH MAP OF PHILIPPINE ISLANDS

Compiled by Philip B. King